GEOPHYSICS

VOLUME XXI, NO. 1 JANUARY, 1956

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Printed in the U.S.A. by George Banta Company, Inc., Menasha, Wisconsin. Entered as second class matter September 7, 1938 at the post office at Menasha, Wisconsin, under the Act of March 3, 1879. Acceptance for mailing at the special rate of postage provided for in the Act of February 28, 1925, embodied in paragraph 4, Section 538, P. L. & R., authorized March 19, 1941. Copyright 1956 by the Society of Exploration Geophysicists.

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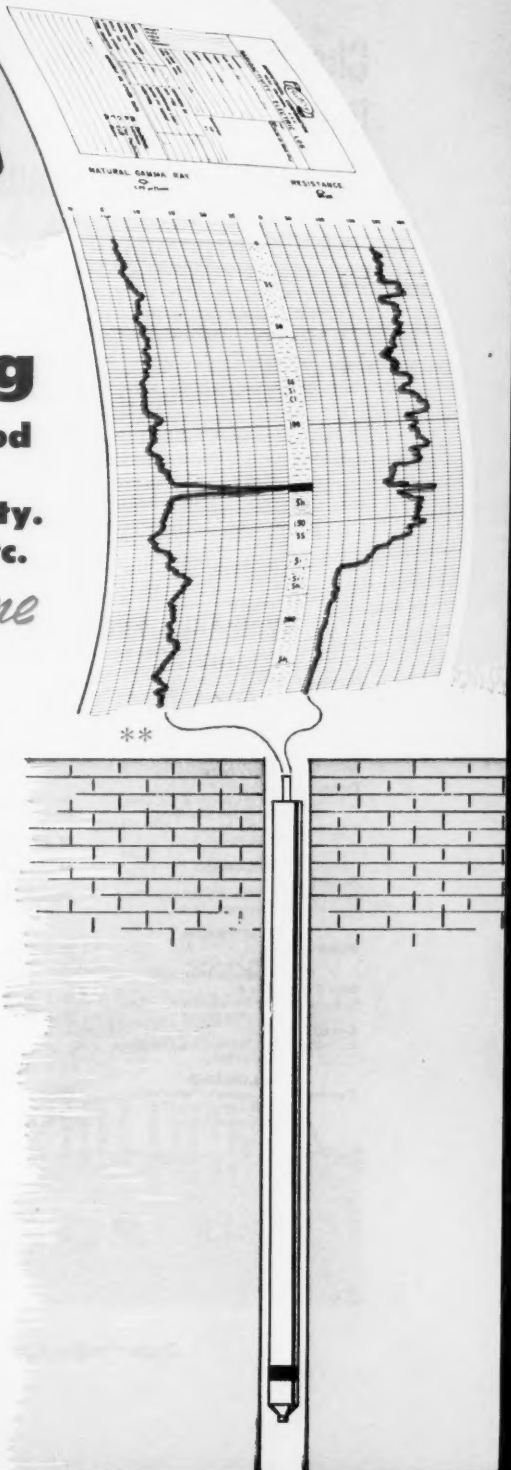

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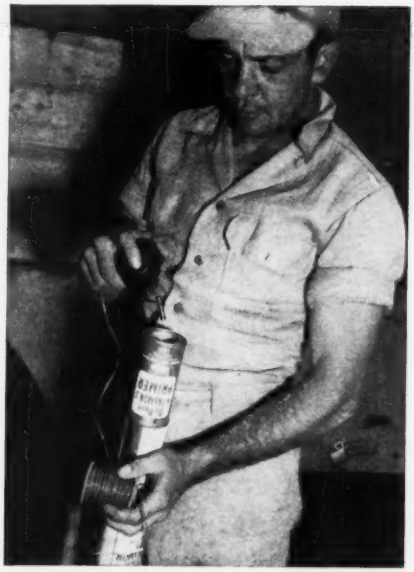

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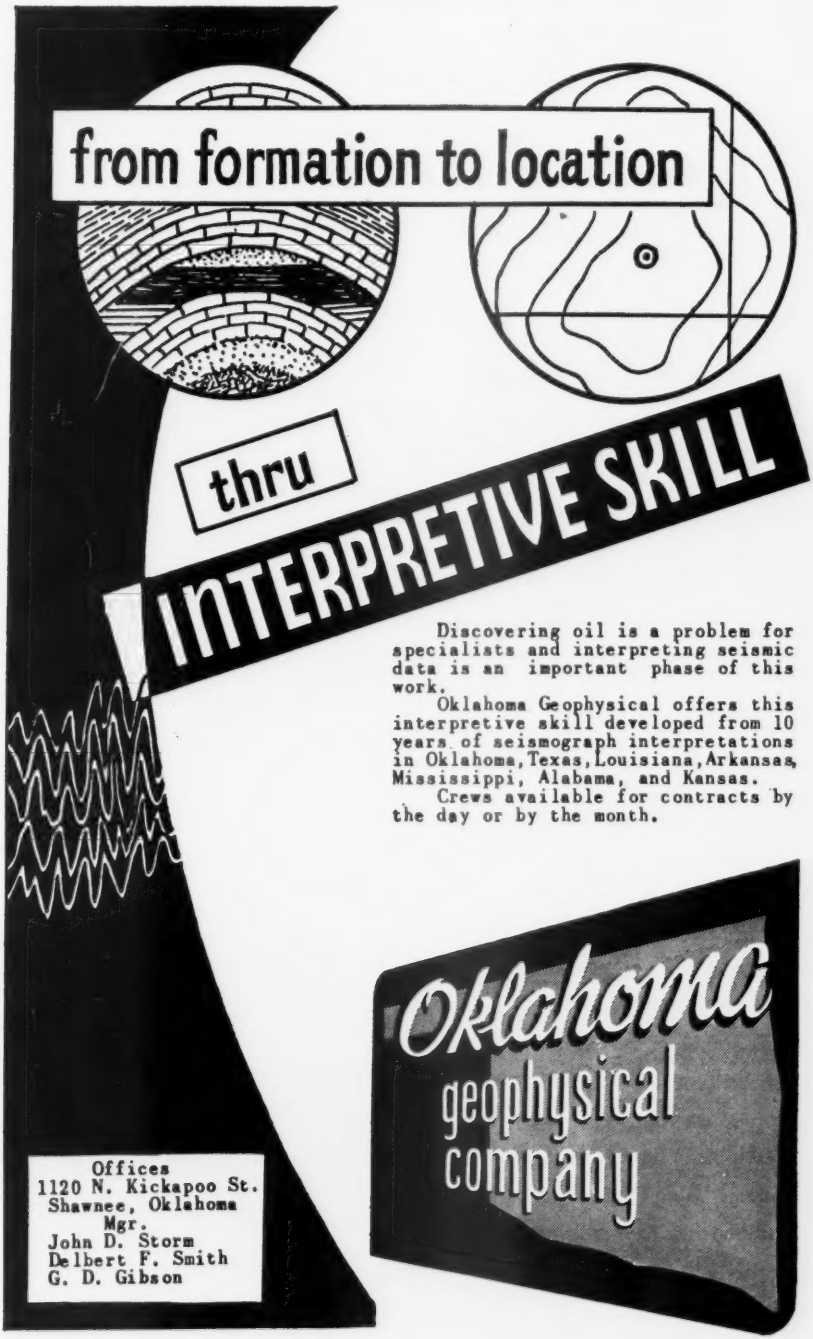
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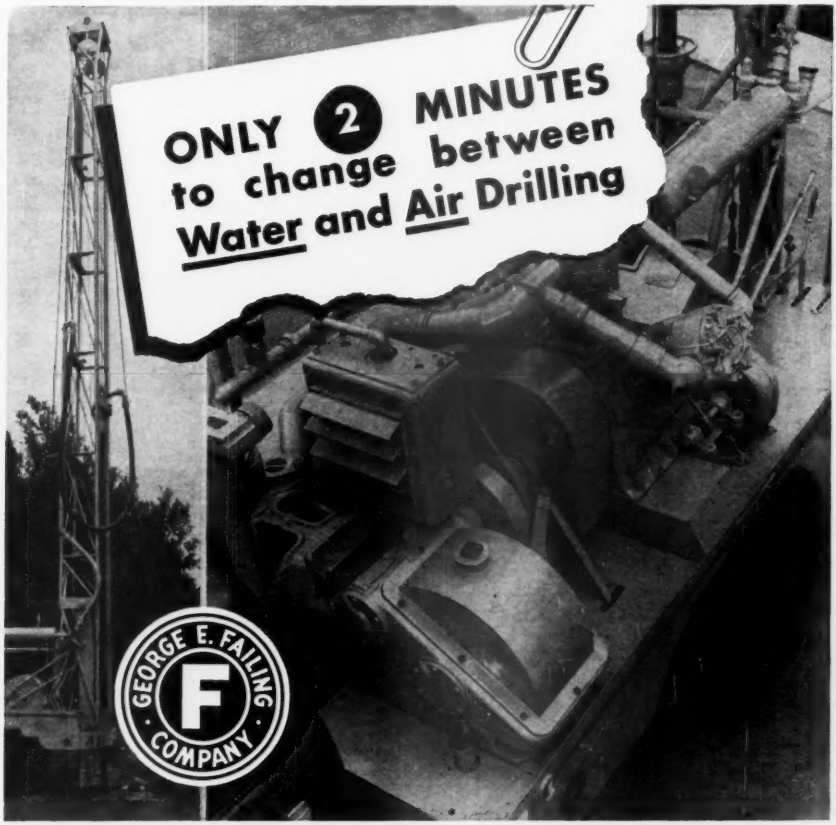

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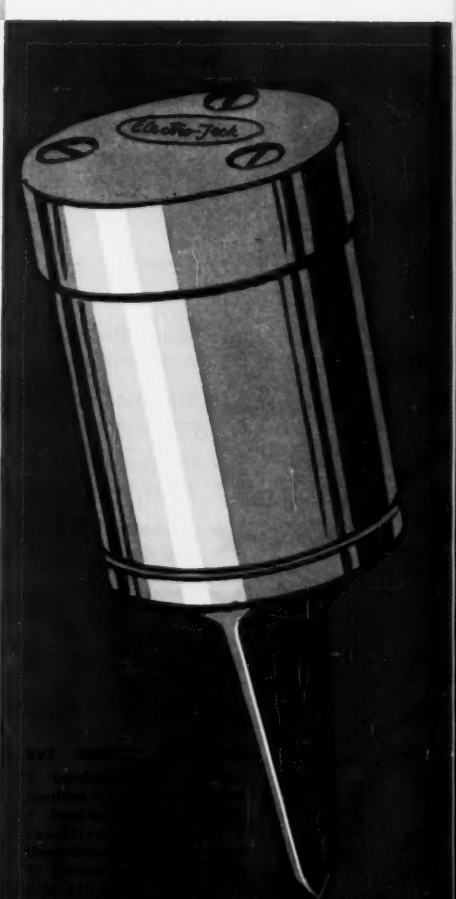

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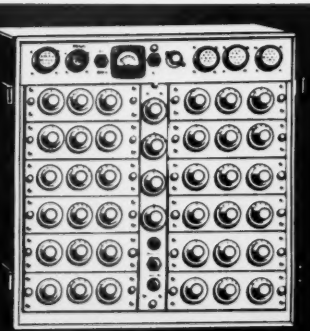

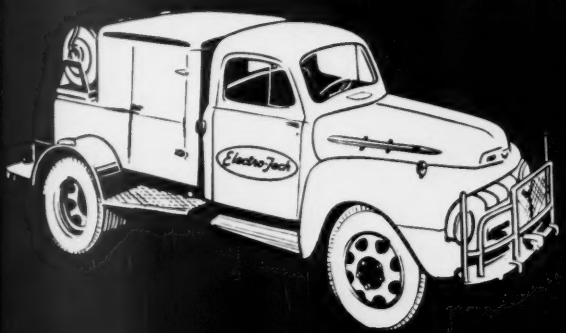

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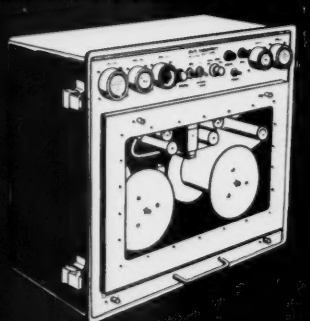

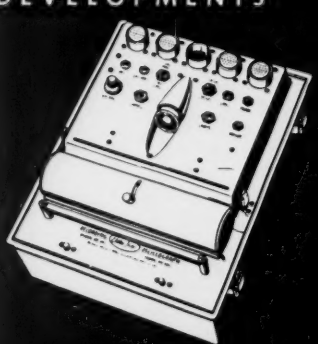

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GEOPHYSICS

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CROSSROADS OF GEOPHYSICS*

PAUL L. LYONS†

I am of the opinion that geophysics, after twenty-five years of modern geophysical exploration, faces a crossroads. On our present road, which exploration geophysics has traversed in a generation, we have established a wonderful record for geophysics in the United States which has also been extended into the far places of the earth. Exploration geophysics originated in the old world, but it found its home in the United States. In the United States we can best examine its record. We have a fairly good record of its applications in this country.

Geophysics found a great, unknown amount of oil in the twenties in the first rush of its use. In the past twenty-five years, paralleling the growth of this society, geophysics has found 22,500,000,000 barrels of oil by its own efforts, and 134 trillion feet of natural gas in the United States. This is between a half and a third of the hydrocarbons found in the United States in that interval. We are presently, as geophysicists, committed to the finding of over a billion barrels of oil per year in the United States, and to over two billion per year in the world. This is an enormous task. The task has not been easy in the past, and it will be even more difficult in the future. I am sure that everyone is well aware of the tremendous difficulties involved in finding commercial oil and gas in the United States, and all these difficulties are not scientific alone.

I should like to call attention to the tremendous acceleration of geophysical development in the last twenty five years. We have progressed from crude instruments to electronic marvels. The only comparable developments in applied science which have paralleled geophysics have been radio-television, nuclear energy, and air conditioning. All were conceived in the past fifty years, all were developed in the past twenty-five years. Yet geophysics at the present time can claim more value of product and more service to mankind.

This acceleration, a modern phenomenon, of geophysical science has rapidly brought geophysics to an economic maturity in the United States. This maturity finds geophysics near its peak effort. It faces an economic crossroads in the United States that it will also shortly face in other petroliferous areas of the earth.

To reach this conclusion, I have studied the growth of geophysics in the last

* SEG Presidential Address presented before 25th Anniversary meeting of SEG at Denver, October 4, 1955.

† Sinclair Oil and Gas Co., Tulsa, Oklahoma.

twenty-five years in order to speculate on its future. Data are available for those years, so that an economic analysis may be attempted. In doing this, it appears that I have followed techniques recently classified by *Business Week* magazine in its feature article of the September 24th issue, entitled "Business Forecasting."

It appears that the conclusions here presented follow the classification known as oaks-from-acorns forecasting. This is based on the simple premise that the future is not identical with the present, but is an outgrowth of it.

Often our opinion of geophysics is based on impressions. I think that a great many operators do not have a precise idea of just how much money geophysics

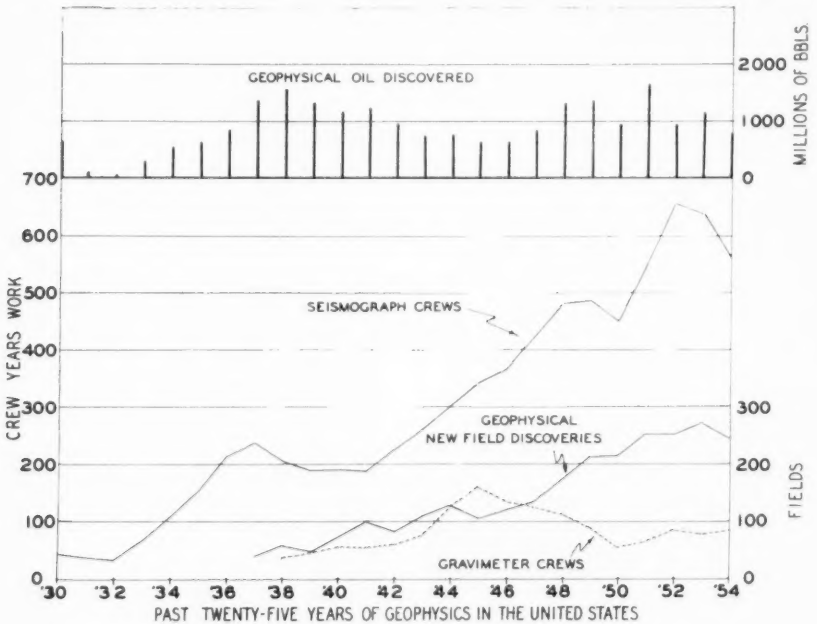

FIG. 1. Geophysical new field discoveries in the United States. Data are derived from Lahee's statistics in AAPG bulletins.

has made for them. In the following charts, it has been possible to adapt the standard figures of the oil industry with those of Lahee and with those of our own society's Eckhardt and Hammer to show rather precisely what the geophysical industry has done for the last twenty-five years, and to set up a sort of standard expectation for geophysical effort. I believe that some of the implications are astonishing, and that some of the trends are disturbing.

People are always complacent and satisfied about charts which are always going up. This chart (Fig. 1) indicates that there is a very satisfactory rise in geophysical new field discoveries in the United States. Indeed these discoveries have averaged 250 new fields for the last four years, and we have all shared the

glow of achievement resulting from these numerous discoveries. Seismograph crew employment has steadily risen for many years to a peak of about 650 crews operating per year in the United States. That peak, reached in 1952, shows signs of again being attained this year, with something like 659 seismic parties now reported in the United States. It should be noted, however, that the substantial oil discoveries attained in the late thirties by geophysics are now being matched with difficulty, and by the efforts of three times the seismic parties. The finality

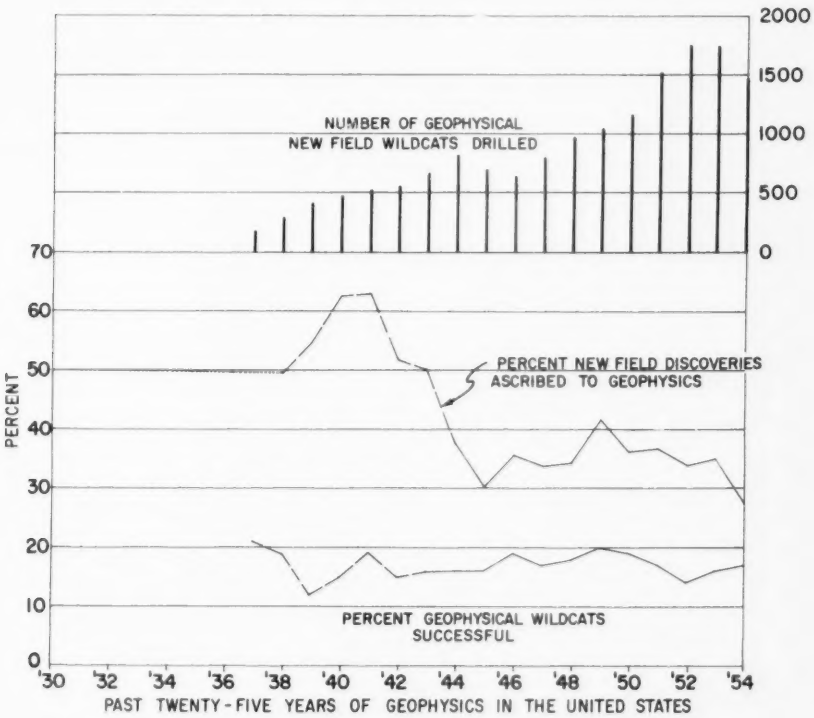

FIG. 2. Geophysical wildcat statistics. Adapted from Lahee.

and speed and accuracy of the gravity meter has halted its rise, but its use has been gratifyingly constant since its peak employment in 1945.

The next chart (Fig. 2) will jar our complacency somewhat. The most gratifying aspect of this chart is that confidence in geophysics is manifest by the fact that more than 1,500 wildcats per year, on an average, have been drilled on geophysical data for the last four years. On the other hand, prior to 1942 more than fifty percent of all wildcat locations were geophysical. Since 1942 this has settled to a third. Of course, we have given our friends the geologists quite a

number of wells to contour, and they have been picking our bones and making geological locations, so that the decline here shown is logical. The most interesting curve is that which indicates how many geophysical wildcats are successful. This has maintained itself in a narrow track between 15 and 20 percent. In other words, one out of six geophysical wildcats have been successful for at least the last sixteen years. There are abundant indications that this percentage was more than doubled in the years preceding 1938, and a 40 percent average is known to

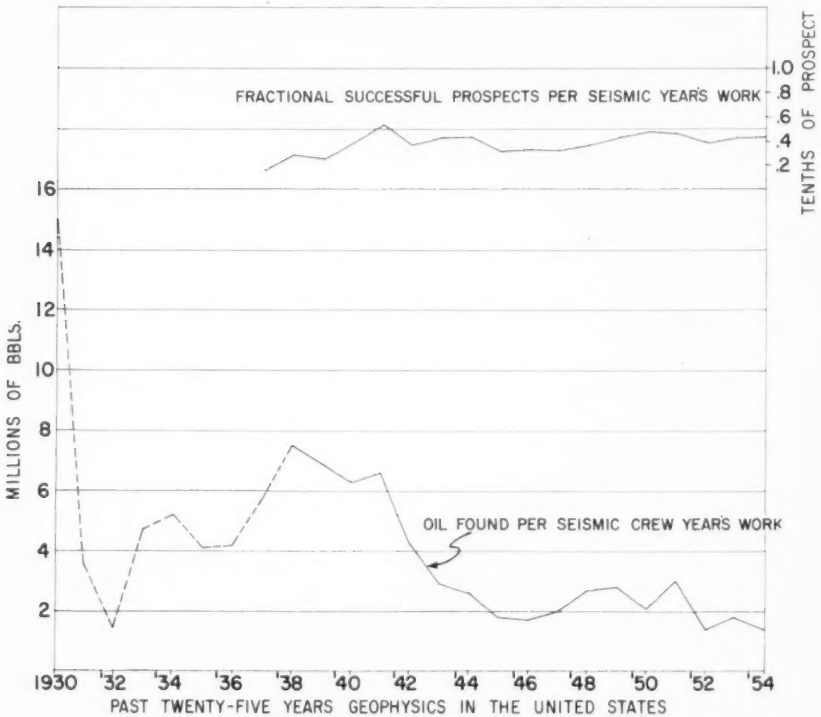

FIG. 3. Oil and prospects found per crew year of effort.

apply to Oklahoma in the early thirties. We must not regard this one in six payout as any slot machine payoff, however, somehow fixed by the earth as the "house." For example, the peak number of geophysical wildcats was drilled in 1952, and the success ratio dipped, correspondingly, to 14 percent. This means that poorer prospects were drilled as industry pushed too hard, and this means that quality prospects must be maintained just to meet the 1 in 6 ratio.

This next chart (Fig. 3) indicates just how exceedingly hard it is to find oil. It illustrates one of the most baffling aspects of the geophysical business. This is

the fact that we must spin our wheels quite a bit in the process of finding oil. We work just as hard on the dry holes. Note that the early seismograph crews found something over 14 million barrels of oil in return for one year of work per crew. This expectation of reward has declined to less than two million barrels per crew per year. This means that if a company intends to find say fifty million barrels per year by geophysics, then it must emply more than twenty-five seismic crews the year round to find the required amount of oil. A remarkable curve is the one which shows the fractional amount of successful prospects found per seismic crew per year. This has settled and maintained a steady four tenths successful prospect per crew year. Thus, it takes an average seismograph party 30 months to find a

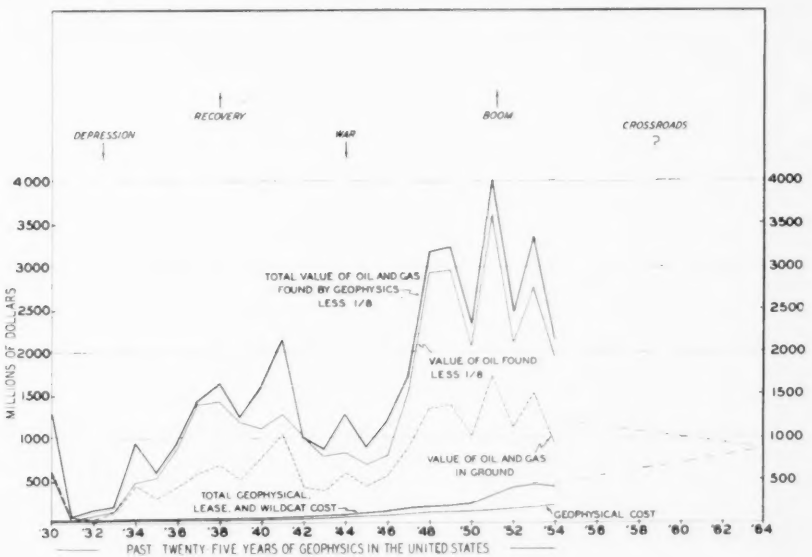

FIG. 4. Geophysical costs and value of oil found by geophysics.

successful prospect. You may also note that the oil in a successful prospect, on the average, has dropped more than two thirds in quantity since 1938, when the average successful prospect contained more than 7 million barrels of oil. We are working on the smaller fish.

The next chart puts the entire geophysical effort of the last twenty-five years on a dollars and cents basis. Our previous charts have still looked pretty good, since they imply substantial returns of oil for geophysical effort and a somewhat stabilized expectation of gain. But we must remember that the past twenty-five years have been the most hectic ones in economic and political history, and the price of oil and gas has fluctuated violently. These are the curves which we should project into the future (Fig. 4).

These are also the curves which indicate the approaching economic crossroads for geophysics. The total value of oil and gas found by geophysics is shown to be quite variable. We must consider a value which has the royalty eighth subtracted, of course. This reached a peak of 4 billion dollars in 1951, and it has dropped alarmingly to a little over 2 billion dollars in 1954, or a drop of almost half. The cost of geophysical work in the United States has grown steadily to 200 million dollars, including research work. But of course, we do not find oil when we have drawn a map of a prospect. We must lease, pay rentals, and drill and equip wells, and put the discovery oil into tanks in order to actually find oil. The cost of this additional discovery effort, which does not include development beyond the first well, is part of the discovery cost. This latter cost is now greater than the geophysical cost, and it may be seen to have grown tremendously in the last four years. It is likely to increase even more, especially since the average depth of wells drilled is greater every year. Now the total figure for these explorations is still only about one quarter of the total value of the oil found. This would be fine, but this is not money in pocket until the oil has been developed, taxed, prorated, and sold. These are variable quantities, and no average figures applicable to all oil are available. But we can count on a present value of oil in the ground, undeveloped, of about one dollar per barrel. This is what people want to pay you for your undeveloped oil, and this seems to be the peak price at lease sales when land values paid are converted to reserves. This curve has been added to show the value of oil and gas in the ground, counting gas as worth, today, 5 cents per thousand cubic feet in the ground. Values of oil and gas in the ground for past years are in similar proportion to the going price above ground.

Now it is at once apparent that this curve is nearing the curve which shows the cost of finding oil and gas. In 1954, the value of oil and gas in the ground found by geophysics was about one billion dollars, and it cost a half billion dollars to find it. Now this is quite a different statistic from the one we usually quote when we divide the unmodified value of all the oil found by all methods by the geophysical cost of exploration and say that oil costs five cents per barrel to find. This figure is nearer a dollar and a half per barrel.

Furthermore, we have apparent two trends which we can painfully extrapolate, so that the costs of finding oil will equal the value of oil found in the United States in about ten years. Now, of course, this is the geophysical crossroads. Even if we consider the tax situation as regards geophysical finding costs, the crossroads will still be there. Even if we effectively pay but half the finding bill because of taxes, we may see the day when the industry exists as a subsidy by virtue of tax writeoffs.

This trend in finding costs is shown percentagewise on the next chart (Fig. 5). Our geophysical finding costs, as defined, have risen from about three percent of the total value of oil and gas found in the thirties to twenty percent in 1954.

Now of course the future won't be as shown, because we will do something about the situation. There is nothing here that can't be remedied by an increase

in the price of oil. But I submit that much foreign oil is still in the discovery stage in which it is very cheap to find, and foreign oil is likely to keep the price of domestic crude at near its present level.

Another obvious solution is to find more oil. This is a scientific solution, and it is one that we can do something about. As geophysicists, this is the road we have got to take.

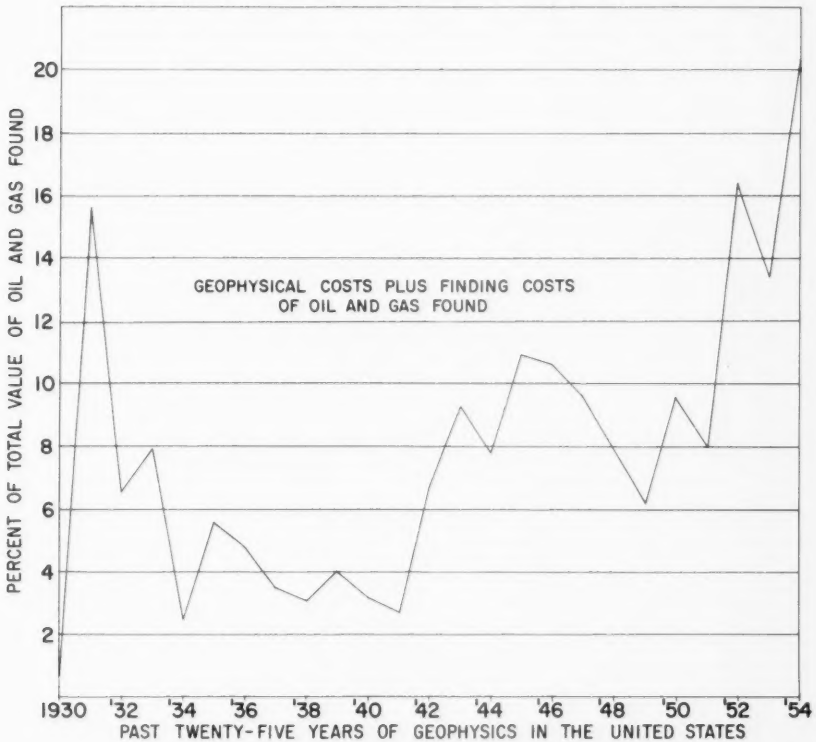

FIG. 5. Geophysical costs plus finding costs expressed as percent value of oil and gas found.

This matter of finding more oil is possible, I believe, simply because there has been no rise in the success ratio of one successful well in six for geophysical wildcats. This ratio is obviously concerned with some natural law, but there certainly is no natural law which says that only one structure in six has oil in it in petroliferous areas. The ratio of dry to producing structures is not known, but the proven dry structure is a rarity. Obviously, the seismograph and the gravimeter,

in our effort to find ever smaller structures, are finding a great majority of anomalies which aren't there as true structures.

To find more oil, then the gravimeter and the seismograph must become more accurate in interpretation. We must cease to develop the spurious or false anomaly, and we must improve our ability to find the true crests of structures.

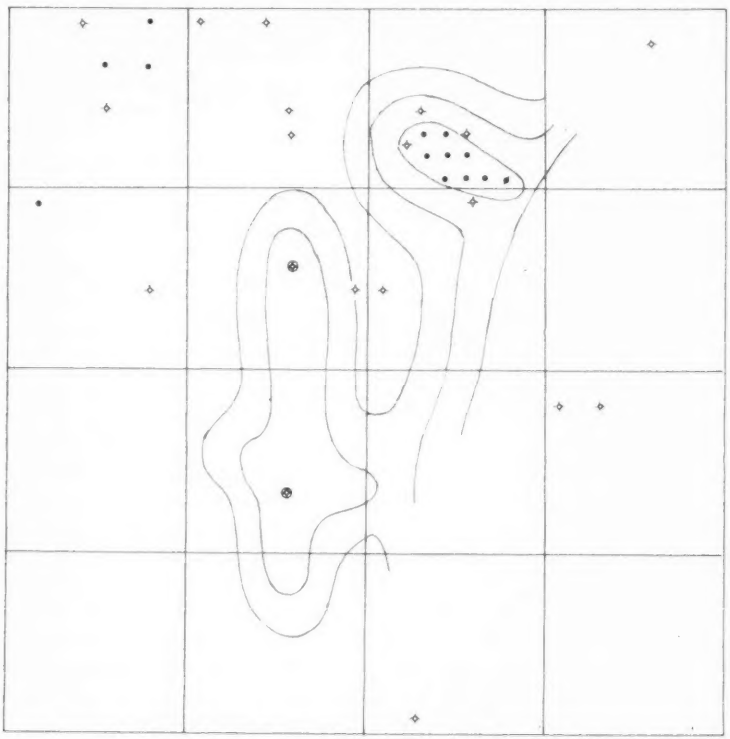

FIG. 6. Two Oklahoma seismic anomalies. Contour interval 25 feet. One was not a structural closure. Mile grid.

And all the while, we must search for stratigraphic traps as well. We must straighten out the wandering, misguided contours on our maps that create natural distrust.

Our ultimate goal should be to acquire assurance that nearly all geophysical anomalies are truly there, precisely as portrayed. We must cease to drill with our background that of a weak anomaly plus hope. Hope is not even a good substitute for geological imagination.

Rather than further decry the situation, I should like to offer a solution. At

this time in most speeches of this type, it is customary to plead for more geological and geophysical coordination. I believe that we have attained all the coordination it is feasible to get, and besides it is similar to one carpenter holding the hammer, and still another carpenter holding the nail. I think that the geophysical interpreter should become a geologist also, and that it is not beyond the interpreter's capacity to know all there is to know about the geology of his

FIG. 7. The non-structural seismic anomaly of Figure 6 coincides with a hill. Topographic contour interval 20 feet. Mile grid.

prospect as well as to know all about the geophysics of his prospect. Now if we concede that the geophysicist can also master local geology, just as he can master Spanish, for example, we are ready for the next step.

We have long since started to tie our geophysical maps to the subsurface geology, and it was logical that that should come first, since we are concerned with deep strata. But we have all but lost sight of the near surface strata, and this is the fly in our ointment, I believe. I also believe that we leave the upper

end of our geophysical calculations dangling, and I propose that after all these years we take another forward step and tie our geophysical calculations to the surface geology as well as to the subsurface geology. The result will greatly refine our resolving power.

What we should seek to do is to eliminate errors arising from the low velocity layer and from the near surface layers underlying the low velocity layer, say down to 2,000 feet. Now we all know the failings of the conventional, routine corrections for the low velocity layer. We often fail to appreciate the fact that the greatest velocity variation in the section occurs above 2,000 feet. We fail

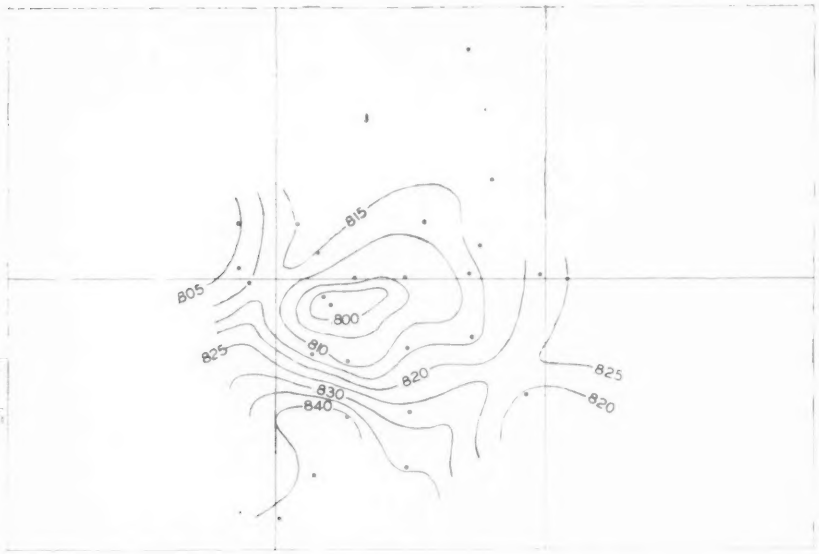

FIG. 8. An Oklahoma seismic time anomaly. Hunton reflection. Contour interval .005 sec. Mile grid. Times to datum.

to appreciate this because we seldom if ever measure the velocity in this section, due to the geometry of the old fashioned velocity test. Yet we do know that there are changes in slope of velocity curves if they are projected through the near surface layers.

There is a good reason for velocity variation in these layers. For one thing, they have usually been buried at greater depths, so that an original velocity due to age and depth was acquired by the layers. Erosion of sediments above has unloaded them, so to speak, and the resulting *relaxed* velocities, and densities as well, are variable. This is particularly true if there are topographic hills around which load the sediments just beneath them. And of course there are velocity

and density variations in the near surface materials when the surface formation varies as a result of dip and there are variations when another formation outcrops.

To emphasize this point, I should like you to consider two small Oklahoma seismograph anomalies, each with less than twenty-five feet of closure indicated (Fig. 6). One was truly there, and the best looking one was not there. Please note in passing, that the 12 producing wells on this map will not pay for themselves and the 19 dry holes.

Examination of the topographic map (Fig. 7) reveals that a hill or ridge, with

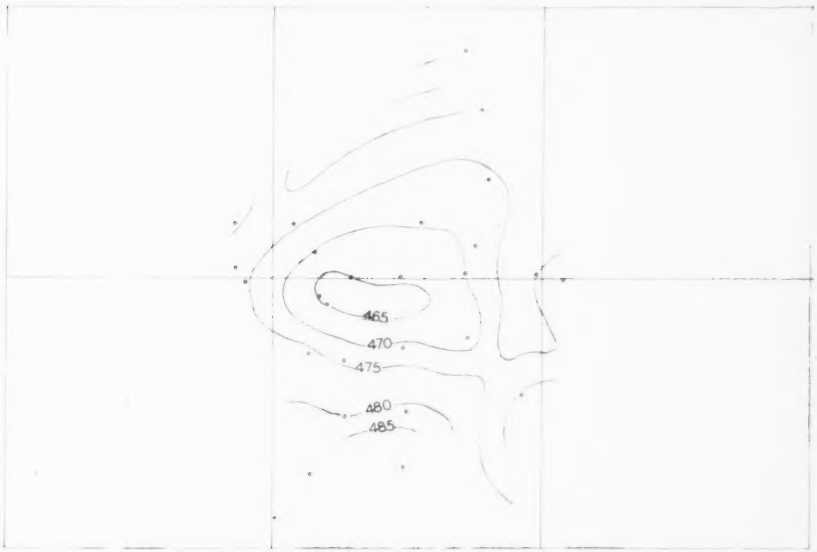

FIG. 9. Shallow Pennsylvanian reflecting time anomaly corresponding to Figure 8. Contour interval .005 sec. Mile grid. Times to datum.

over 100 feet of relief, which is four times the subsurface relief we seek to find, has obviously raised the velocity of the near surface layers so as to create a minimum time anomaly. Such examples are common. In leaving this one, I submit to you that the solution is not the obvious remedy of discarding all anomalies under hills.

A much worse situation is presented by the near surface velocity anomaly occurring beneath flat topography, and unsuspected in routine conventional calculations. Here is a seismograph anomaly with quite a bit of time relief (Fig. 8). This is also in Oklahoma, and it is worth drilling if true. Examination of the shallow reflections produces a similar picture, with somewhat less relief at 2,000′

(Fig. 9). Now I submit that a geophysicist, acting as a geophysicist alone, would perhaps subtract the shallow time values from the deeper values and come up with a satisfactory "thinning" or lessening of the time interval over the supposed structure. This would serve as a check, and he would pass it as a valid structure. But in this area there has been a great number of shallow wells drilled to 2,500 feet on a stratigraphic trap. It was possible to find and to correlate all these old logs (Fig. 10), and only regional dip was apparent at 2,000 feet in the section. Combination of the times and true depths to this horizon proves the existence of a pronounced velocity anomaly above 2,000 feet, with 600 feet of velocity relief,

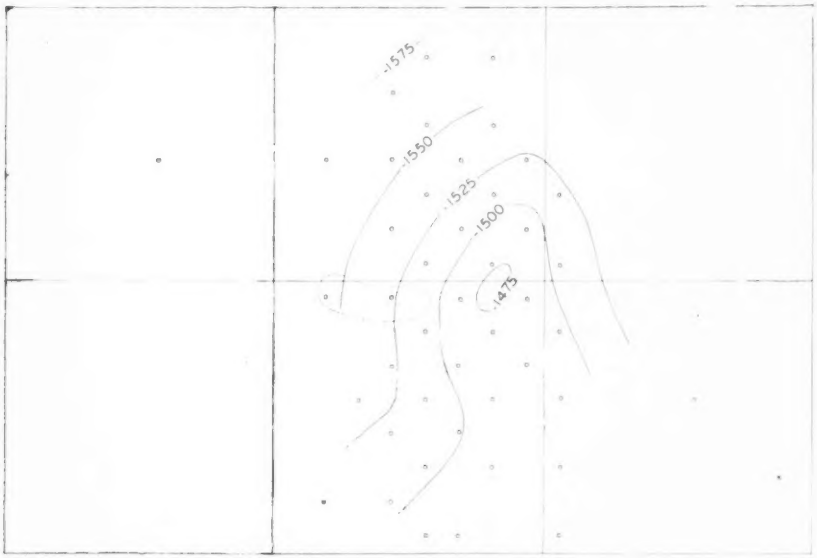

FIG. 10. Actual structure derived from well control as shown for Pennsylvanian reflection horizon of Figure 8. Contour interval 25 feet subsea. Mile grid.

which is 6 percent, occurring in less than a mile (Fig. 11). Knowing the true attitude of the 2,000 foot bed, we can use it as a datum, build the structure downward, and arrive at the true deep picture in terms of depths (Fig. 12). Not only is it markedly different from the first picture, it is not worth drilling in the area of its occurrence.

Now here is a proven instance of near surface velocity variation. No conventional correction, and no use of that rubber yardstick, the overall velocity overlay, will anticipate this situation.

I submit that the answer is here apparent. The correct way to eliminate time variations for which we cannot correct, and which arise in the low velocity layer

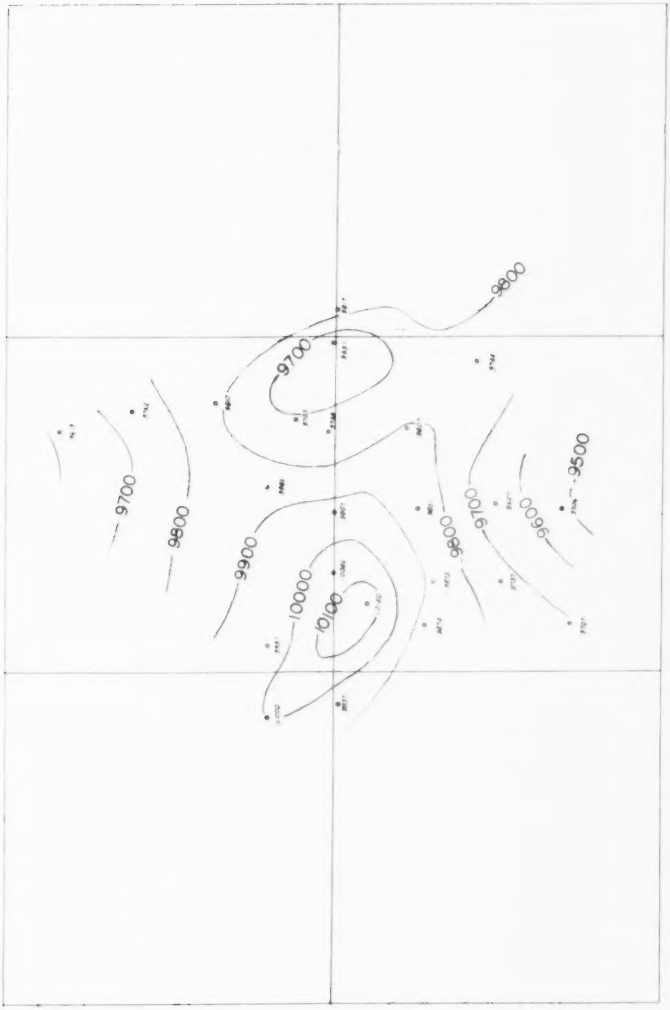

FIG. 11. Velocity anomaly derived from combination of data from Figures 9 and 10. Seismic control points shown. Mile grid. Velocity in feet per second.

in the near surface layers, is to ignore them. Let us return to surface geology, derived from the actual outcrops, from well logs, from shot hole logs, and areal geologic maps, from core drill maps, from photogeology, and from refraction first events on the seismic records. Let our time datums be parallel to the surface structure. Let us construct our depth maps by working downward from this datum, a layer at a time, utilizing the time intervals between successive reflections. We can anticipate velocity variations in one deep geologic *unit;* we cannot anticipate the net velocity variation of a dozen or so geologic units lumped together and expressed as an overall velocity overlay.

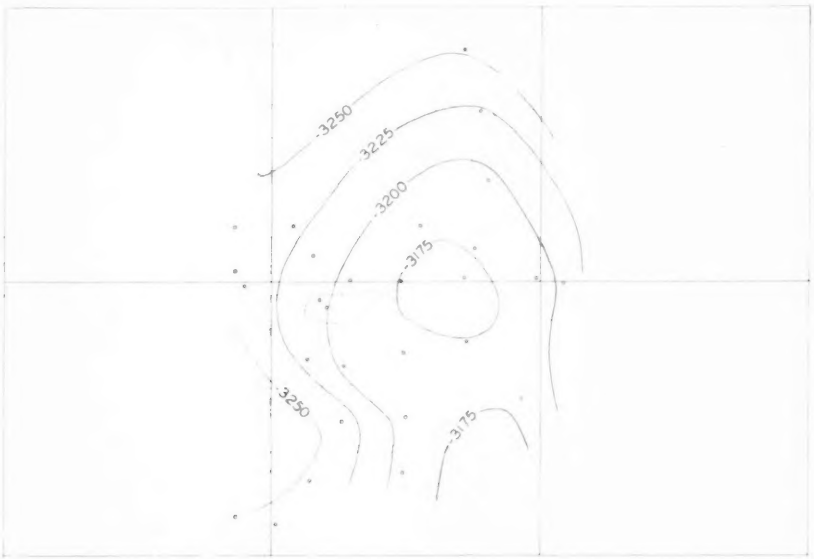

FIG. 12. Seismic depths to Hunton present different picture than the time map of Figure 8. Mile grid. Contour interval 25 feet.

I also submit that the study of time variations in successive small geologic units here suggested is a lucrative field for the isolation of stratigraphic traps. I submit that the measurements of time intervals between successive reflections are the most accurate measurements afforded by the seismic method. We now have high resolution, high frequency instruments available to bring in near surface reflections. The interval studies may be handled by punched card methods. Let's stop multiplying one time by one velocity to get depth. Our velocities are really determined by geology, not mathematical formulas.

As for gravity prospecting, the inverse square law lends tremendous importance to any near surface change in density. The gravimeter is more plagued

than the seismograph with spurious anomalies. If we derive the effects of the surface geology on the gravity picture, we may be able to eliminate many anomalies due to these effects, so that the valid anomalies remain and can be trusted.

I have proposed a change in our methods of interpreting geophysics to anticipate an approaching economic dilemma. If this mixing of finance and interpretation seems incongruous, I can only quote Dr. E. A. Eckhardt, who once said, "The normal conduct of geophysical operations involves a complex series of compromises among considerations of geology, geography, geophysics, finance, law, and management policies."

When I first joined a seismograph crew, I never entirely unpacked my suitcase. I was afraid of the geophysical business. Our crew would either find all the oil there was to be found, or it would not find any. In either case, we could get the gate. I still don't think we should be complacent, and I think we work best when we are scared.

We should be scared of our success ratio. It should be much better, perhaps one in two. We should be scared of, and respectful of, our superior modern instruments, lest we become too dependent on mechanical crutches. We should be bothered by the fact that we spend far too little money on interpretation. We should be bothered by the fact that the present tax setup penalizes the financing of intelligent long-range exploration programs. We need more plow-back money. We should be scared for the future of geophysics. And we should do something about all these items.

We should not be scared that there is little more oil to be found in worked over areas. The United States is still far from being worked over, and there is still abundant oil to be found. We should not be scared of our capabilities. The papers presented at our meetings justify our confidence in that respect.

But let us not forget that we may face an economic crossroads. Geophysics is a fascinating business, and it is a rare privilege to us all to be engaged in it. But it must continue to be a profitable business to exist, and it is up to all of us as geophysicists to see that it remains profitable. Some day, of course, the last shot hole will be fired, the last station run. But that will be in the old age of geophysics, and not in our time. Today exploration geophysics is still kept young by our efforts, and most of our oil and our mines are yet to be discovered.

Thanks are expressed to the Sinclair Oil and Gas Company for permission to publish this paper.

GEOPHYSICS, VOL. XXI, NO. 1 (JANUARY, 1956), PP. 16–40, 7 FIGS.

TECHNICAL PAPERS

SEISMIC WAVE ATTENUATION CHARACTERISTICS FROM PULSE EXPERIMENTS*

FRANCIS COLLINS† AND C. C. LEE†

ABSTRACT

Laboratory data on the transmission of stress waves in rocks indicate that the attenuation exponent (db/ft) for steady state sine waves is roughly proportional to frequency in dry cores at atmospheric pressure. Measurements of the effects of pressure and water saturation, however, show that much more work is required before laboratory results can be extrapolated to conditions in the earth. Field experiments avoid these problems, but not, of course, without introducing others. The field tests and theoretical studies of Ricker indicate that the attenuation exponent is proportional to the square of the frequency at low frequencies; these results have not, however, been accepted unreservedly. We propose further experiments of the type conducted by Ricker, but with emphasis on recording the wave at several distances so that the changes in shape can be observed as the wave travels through the medium.

To use such data to determine the attenuation exponent and the wave propagation equation, we propose that the pulses be converted to equivalent steady state sine wave data by Fourier integral analysis. Geometric effects in the particular experiment can be eliminated by mathematical analysis and the attenuation exponent calculated from the steady state magnitudes and phases at different distances. The basis of the analysis method is the fact that the manner in which the attenuation exponent appears in the harmonic solution of the most general linear wave equation is independent of the manner in which it varies with frequency. Hence at each frequency the attenuation exponent can be calculated from the steady state data for that frequency. The method is applied to data obtained in a quarry sandstone. Although the results are not consistent for different transmission distances, it is believed that data from additional experiments of this kind can be used to determine the attenuation exponent and the wave propagation equation.

In formulating the method, the Boltzmann superposition principle is used in which the general three-dimensional stress-strain relations for an isotropic material require two elastic constants and two memory functions. A preliminary study of the memory function for dilatational waves yields some interesting limitations on possible functions when we impose the restriction of elastic behavior with static stresses and strains. If the Laplace transform of this function is analytic at the origin, then the attenuation exponent increases with the square or some higher even power of the frequency at low frequencies. To obtain any other variation, the memory function transform must have a branch point at the origin (poles and essential singularities are ruled out). No memory function will yield an attenuation exponent precisely proportional to frequency over any frequency range, but a class of memory functions may exist yielding an attenuation exponent proportional to frequency raised to a power arbitrarily close to unity at low frequencies. This analysis is based on the assumption of linearity, which we do not wish to abandon until forced to by experimental data.

INTRODUCTION

The classical elastic equation is used as the basis for most of the theoretical interpretation of observations of stress waves in the earth. A fundamental consequence of the assumptions of the elastic theory is that a plane wave is transmitted without attenuation and without change of form. The continued use of the elastic wave equation arises, we believe, not from a general failure to recognize that it is inadequate in many cases, but from the rarity of experimental

* Presented at the Annual Meeting of the Society at New York on March 30, 1955. Manuscript received by the Editor April 26, 1955.

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data on earth materials to support a more general theory of wave propagation.

The attenuation of other materials such as metals, glasses, polymers, and acoustic absorbers has been investigated extensively. Systematic treatments of the theory and experiments are available in books (Alfrey, 1948; Zener, 1948; Kolsky, 1953), and these in turn give many references to research papers. The only widely applicable general rule is that the attenuation exponent, expressed for example in decibels per foot, is proportional to some power of frequency over a substantial frequency range. The frequently cited data of Wegel and Walther (1935) illustrate this situation. For the metals and glasses which they tested, they found the attenuation exponent proportional to f^n with n ranging from 0.87 to 1.54. On the other hand, Quimby (1925) found for similar materials that the attenuation exponent was proportional to the square of the frequency. This result is in accordance with one of the simplest viscoelastic theories, the Voigt or Kelvin model of a solid in which stress is the sum of two terms depending on strain and strain rate. These differences have never been satisfactorily resolved.

In some cases the attenuation exponent varies in a complicated manner with frequency (Zener, 1948, p. 92). In a few cases it has been possible to relate the behavior of attenuation with frequency to the molecular, crystalline, or grain structure of the material. No general theory of attenuation in solids has, however, emerged from this accumulation of data and special theories. Furthermore, most of these experiments have been conducted at very high frequencies compared with the frequency range of interest in geophysical exploration. Hence it appears doubtful that these results can be extended to aid in determining an equation to describe the propagation of earth waves. It appears that for this purpose we are present limited to using primarily the results of experiments on earth materials.

PUBLISHED DATA ON EARTH MATERIALS

In considering the published information on rocks and other earth materials, we can cite three papers (Birch and Bancroft, 1938*a*; Born, 1941; Bruckshaw and Mahanta, 1954) reporting laboratory measurements of attenuation exponent as a function of frequency, and one paper (Ricker, 1953) reporting field experiments which are correlated with the Voigt (or Kelvin) viscoelastic theory. Other measurements at a single frequency are available, notably those given in U.S. Bureau of Mines reports (e.g., Windes, 1949), but these are not particularly pertinent to the present discussion.

Birch and Bancroft (1938*a*) measured the attenuation exponent in a granite cylinder 8 feet long and 9 inches in diameter, covering a frequency range of 140 to 1,600 cps by using several modes of longitudinal, torsional, and flexural vibrations. They reported that their measurements were not sufficiently precise to give a definite correlation of attenuation with frequency, but that very roughly the attenuation appeared to be proportional to frequency.

Born (1941) experimented with bars of shale, limestone, sandstone and cap rock of various lengths up to 6 feet, some of them fabricated by cementing together shorter sections of core. For dry cores, he also found that the attenuation exponent was proportional to frequency. The addition of a very small quantity of water, however, introduced another loss mechanism, and the attenuation exponent appeared to be the sum of two terms, one proportional to frequency and one proportional to the square of the frequency. Most of Born's data are at frequencies above 500 cps; on the 6-foot cap rock core the range was extended to the neighborhood of 100 cps by the use of lateral vibrations.

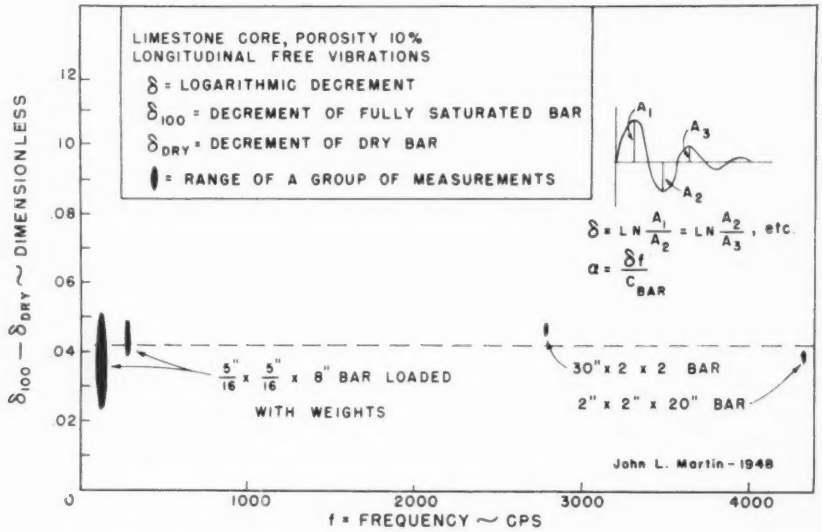

FIG. 1. Effect of water saturation on attenuation of longitudinal free vibrations in a limestone core. Within the accuracy of the measurements the increase in logarithmic decrement from zero to 100% saturation is independent of frequency. In Born's (1941) experiments small amounts of moisture caused an increase in decrement which was proportional to frequency.

Bruckshaw and Mahanta (1954), using lateral vibrations, made measurements on several different rocks over the extremely interesting range of 40 to 120 cycles per second. Assuming that the cores were dry, their data are consistent with the results of Born, and of Birch and Bancroft. The attenuation exponent is proportional to frequency within the accuracy of the experimental method, although there is an indication of a more rapid increase at the lower frequencies, 40 to 70 cps.

John L. Martin[1] carried out a series of experiments on limestone bars in 1947 and 1948, and some of his results, previously unpublished, are shown in Figure 1.

[1] The Atlantic Refining Company, Dallas, Texas.

In this work the bars were excited and then photographs were taken showing the exponentially decaying free vibrations. The logarithmic decrement δ, the natural logarithm of the ratio of successive peaks, was measured on these records. Figure 1 gives the difference between the decrements for fully saturated and for dry cores. Using this difference tends to reduce variations arising from losses in the apparatus (particularly at low frequencies where the bar was loaded with weights). These data indicate that the increase in decrement due to fully saturating the cores with water is roughly independent of frequency. This result would not be expected from the data of Born (1941) in which the addition of very small amounts of moisture produced an increase in decrement which was proportional to frequency. Although Figure 1 gives the change in decrement when the rock is saturated with water, this is believed to be very nearly the decrement of the saturated rock alone, since at high frequencies, where the best accuracy was obtained, the decrement of the dry rock was very small. If these data are valid, the attenuation exponent varies roughly linearly with frequency for this saturated rock.

From these four sets of laboratory data, it appears that the attenuation exponent for rocks is approximately proportional to frequency in and far above the range of interest in geophysical exploration. An analysis will be presented below showing that no *linear* theory can lead to precisely this result, and hence, if this hypothesis were used as a starting point, we would have to construct a non-linear wave equation based on a non-linear stress-strain relation. It will also be indicated below, however, that a linear theory can probably be developed which will lead to attenuation exponent proportional to frequency raised to a power arbitrarily close to unity at low frequencies. Since the data are not sufficiently precise to require variation with exactly the first power of frequency, it therefore appears possible to construct a linear theory which will give a good approximation to the data.

Actually it seems clear that much more data which are reliable must be accumulated before we can justify a large amount of theoretical work to develop a linear theory in which the attenuation exponent is approximately proportional to frequency. The work of Born (1941) and of Martin shows that both the attenuation exponent values and the manner of their variation with frequency are extremely sensitive to moisture content. This point has also been demonstrated by Obert, Windes, and Duvall (1946). Zener (1948, p. 126–132) gives an interpretive discussion of attenuation effects in a two-component system consisting of one elastic and one viscous material. In geophysical exploration, stress waves are propagated primarily through completely water-saturated materials, so it is evident that this question must be given very serious consideration.

Further, Birch and Bancroft (1938*b*) have shown that the attenuation exponent decreases greatly with increase of pressure. Their work on elastic constants at high pressures also shows that at surface conditions the structure of the rock is loosened and its behavior cannot be expected to give a reliable indication of its behavior under pressure.

Thus not only is a large amount of laboratory data needed to establish the variation of attenuation with frequency for various earth materials, but particular emphasis is needed on the effect of water saturation, pressure, and to a lesser extent temperature, as well as on all other experimental conditions and core preparation procedures which need to be considered to transform the laboratory data so that they will describe the behavior of these materials as they exist in the earth.

Field experiments can be considered as a possible alternative which avoids some of the serious problems of interpreting laboratory results. This alternative introduces new problems of its own, of course, and it is not yet clear whether one of these approaches will prove to be superior to the other or whether they will both be needed.

At present we can cite only one paper (Ricker, 1951 or 1953) giving results of field experiments intended to establish a definite theory of wave propagation by measuring waves travelling directly from a dynamite charge. (Correlations from reflection records are not deemed to be sufficiently accurate for this purpose.) Ricker compared his results with a mathematical theory of spherical dilatational waves derived from what is most frequently called a Voigt model of a viscoelastic material (a Voigt solid is a linear material in which stress is the sum of strain and strain-rate terms). Some writers trace this model to Kelvin (Mattice and Lieber, 1954), and Ricker himself attributes it to Stokes. We are not attempting to resolve this historical problem, which may be partly a matter of interpretation, but make these references to aid in identification. We are in the habit of using the term "Voigt solid" for this model.

The mathematical development is given primarily in earlier papers (Ricker, 1943 and 1944). According to the theory, at large distances from the shot point an electromagnetic seismometer, recording the velocity of earth movement, will detect a wave whose breadth will increase as the square root of the distance (or of the travel time of the center). In Figure 12, Ricker (1951 or 1953) gives a graph of some 50 points with wavelet breadth plotted against travel time on logarithmic scales. The scatter of the data is evident, but a straight line passed through the points by least squares has a slope of 0.508 which compares very favorably with the theoretical slope $\frac{1}{2}$ corresponding to wavelet breadth increase with the square root of travel time. This is the most convincing evidence that the shale in which Ricker carried out these elaborate experiments propagates stress waves in accordance with the theory derived from the Voigt model. The plots of amplitude against travel time do not show quite such excellent agreement with the theory, but this result could be expected since the amplitude is more sensitive to some random variables than is the wavelet breadth.

If the shale tested by Ricker behaves as a Voigt solid, then a consequence of the theory is that, over the low-frequency range of interest in seismology, the attenuation exponent is proportional to the square of the frequency. This result is to some extent at variance with the laboratory data discussed above in which attenuation appears to be proportional to the first power of frequency. There is

some temptation to explain these differences on the ground that the field experiments represent the true situation and the laboratory experiments were not conducted under conditions suitable for interpretation to field work. This position is reinforced by Born's data in which the addition of moisture to the cores, a step toward field conditions, introduced a term increasing with the square of the frequency.

Ricker's interpretation has not, however, been accepted without reservations. In a written comment on Ricker's paper, S. Kaufman pointed out a discrepancy in the comparison of theoretical and observed wave forms (Ricker, 1951 or 1953). All comparisons of wave form were made with theoretical forms calculated for a dimensionless distance parameter R equal to 25. This numerical distance is related to actual shot distance r by $R=2\pi f_0 r/c$, where c is the wave velocity and f_0 is the very convenient and intuitively significant "transition frequency" devised by Ricker as a parameter to express the damping of dilatational waves in a Voigt solid. Ricker's average values of f_0 and c as determined from the field experiments are 8,000 cps and 7,000 ft/sec, and if these values are used with $R=25$, the calculated shot distance is $3\frac{1}{2}$ feet, unreasonably small in view of the actual distances used. In replying to this comment, Ricker expressed the belief that this discrepancy could be explained by the fact that the shale is inhomogeneous—the wave form is determined in the vicinity of the shot in a region of low transition frequency, and does not change greatly after reaching deeper regions of higher transition frequency (lower attenuation). This explanation does not appear entirely satisfactory if the conditions are considered in more detail. In replying to other comments, Ricker mentions very low transition frequencies at shallow depths, less than 100 feet, but gives the variation of f_0 from 100 feet down as an increase from 2,000 cps to 8,000 cps. All the observed wave forms used for comparisons in the paper were recorded from shots at 100 feet or more, and the geophones were at greater depths than the shot, so that it appears that the lowest value of f_0 which can be selected is 2,000 cps. If this value is substituted in the above equation, the calculated shot distance r is 14 feet, still small in comparison with the actual distances.

Van Melle (1954) has based an objection on energy considerations. Referring to an earlier paper (Ricker and Sorge, 1951, which contains enlarged photographs of some of the observed waves given in Ricker's 1951–1953 paper), Van Melle obtains sufficient data to calculate approximately the actual energy, kinetic plus potential, in the travelling wave. Then, using Ricker's attenuation theory and extrapolating back toward the shot, he finds that at a distance of 72 feet from the shot the wave should contain roughly $1\frac{1}{2}$ times the total chemical energy of the charge, and at a distance of 36 feet the wave energy should be 7 times the charge energy.

There is one other source of data, not readily classifiable with the laboratory and field experiments just discussed, which can be used to calculate the attenuation of earth waves. By analysis of earthquake surface waves, Ewing and Press (1954*a* and 1954*b*) have determined attenuation values in the frequency range

of 0.003 to 0.007 cycles per second. Their results suggest that the attenuation exponent is proportional to frequency rather than frequency squared, and the numerical values are consistent with those of Birch and Bancroft at higher frequencies. This agreement between sets of data at such widely different frequencies, bridging the range of geophysical exploration, is quite striking.

PROPOSAL FOR FIELD EXPERIMENTS

Attempting to take into account all the published experimental data and theoretical analysis, we do not find it easy to reach any definite conclusion. We are inclined to fall back on the generally safe position that further study is required. We have already alluded to some of the questions involved in choosing between laboratory experiments on small specimens and field experiments in large volumes of homogeneous material under natural conditions of pressure and water saturation. Here again no general conclusion seems justified, but at present we favor further field experiments of the general type carried out by Ricker.

We propose experiments in which the wave shape is recorded by geophones at a number of different distances, not too widely spaced, so that the change in wave form can be examined as the wave passes through the medium.

The mathematical analysis of such experiments can be carried out from at least two different viewpoints. An indirect approach is to select some theoretical model, such as the Voigt solid used by Ricker, and, using the observed wave form at some distance as input, calculate the theoretical wave form at some greater observation distance and compare it with the observed wave. Such a calculation can be carried out between any pair of geophones or for a series starting with the nearest geophone as input. This procedure involves trial and error at the initial step of assuming the theoretical model for the medium.

We have been considering the possibility of a more direct approach in which the series of observed wave forms at different distances is converted to equivalent steady state data, such as would be obtained if a sine wave generator could be used instead of a shot, by Fourier integral analysis of the pulses. In the steady state solution of any linear wave equation the attenuation exponent appears in the same way regardless of the manner of its variation with frequency; hence these equivalent steady state data can be inserted in this equation at each frequency, leaving the attenuation unknown. The solution of this equation for attenuation at each frequency will require trial and error or other numerical methods in practically every case, but this trial and error is much less recondite than that involved in what we have called an indirect approach.

One of the objects of the following discussion is to explain this procedure in greater detail, primarily with respect to a particular simple geometrical situation, the propagation of spherical dilatational strain waves. Following the outline of the general method, the results obtained with one particular set of data will be given. While these results are not conclusive, they are not so discouraging as to rule out further efforts.

As a preliminary to outlining the method, we will discuss the most general linear stress wave equation, making reference to general linear stress-strain relations and calling attention to some basic mathematical conditions which we feel to be important.

FORMULATION OF GENERAL LINEAR THEORY OF STRESS WAVES

In linear elastic theory the components of stress are written as linear combinations of the components of strain (generalized Hooke's law) and no rate or hereditary effects are present—the strain at a point instantly adjusts to the stress. This instantaneous response corresponds to the fact that there is no energy dissipation and no dispersion when a plane stress wave is transmitted through an elastic solid. To introduce dissipation into the theory, we must add time effects of some kind to the stress-strain relation. Let us for the moment ignore complications arising from consideration of shear stresses and two or three dimensions, and use as an example a plane normal (compression-tension) stress in a homogeneous isotropic material. In rectangular coordinates let the non-zero stress component σ be in the x-direction, and let ϵ be the corresponding strain. If the material is purely elastic, then the stress-strain relation is

$$\sigma = (\lambda + 2\mu)\epsilon, \qquad \text{(elastic)} \tag{1}$$

where λ and μ are Lamé's constants. This discussion could also be carried out with reference to compression and tension in a uniform thin bar, in which case we would replace $\lambda + 2\mu$ by Young's modulus.

The simplest way to include a time effect is to add a term with a stress or strain derivative, for example

$$\sigma = (\lambda + 2\mu)\left(\epsilon + \frac{1}{\omega_0}\frac{\partial \epsilon}{\partial t}\right). \qquad \text{(Voigt)} \tag{2}$$

introducing a stress proportional to the strain rate. This is the Voigt or Kelvin material used by Ricker, and ω_0 is as previously mentioned the parameter selected by Ricker and called the transition frequency (rad/sec).

The next step in producing a more complicated model is the addition of an arbitrary number of derivatives of both stress and strain, resulting in

$$\sigma + \sum_{k=1}^{m} a_k \frac{\partial^k \sigma}{\partial t^k} = (\lambda + 2\mu)\left[\epsilon + \sum_{k=1}^{n} b_k \frac{\partial^k \epsilon}{\partial t^k}\right]. \tag{3}$$

The behavior of a solid satisfying (3) can be visualized with a set of suitably connected springs and dashpots. Considering shear stresses only, Alfrey (1948, p. 537–556) describes these models and gives a full discussion of seven mathematically equivalent methods for specifying behavior such as (3), describing exact and approximate procedures for converting from one method to another.

It might be thought that a more general relation than (3) could be constructed by including integrals and repeated integrals of stress and strain as well as

derivatives. In physical applications, however, it seems reasonable to assume that such a relation could be differentiated a sufficient number of times to remove all the repeated integrals. In this connection we might mention a condition which we feel should be imposed on relations such as (3), namely, a requirement of satisfactory static behavior. That is, if a stress is suddenly applied at $t=0$, we expect the final condition at infinite time to satisfy the elastic relation (1), regardless of the manner in which the strain varies with time in achieving its final value. This requirement implies that the undifferentiated stress and strain terms must appear with non-zero coefficients, as indicated in (3), in order that (3) will reduce to (1) under static conditions, when all time derivatives are zero. On this basis, we reject the Maxwell solid and similar models in which the strain increases without limit under a constant applied stress (Lee and Kanter, 1953). We recognize that in studying wave propagation we do not have to deal with static conditions, and hence that it might not be necessary to impose this requirement to obtain a sufficiently good approximation for our purpose; however, we feel that at this time this condition is a desirable safety precaution to include in further developments of the theory.

This static elastic behavior requirement also has an effect on the manner in which, finally, we formulate the most general stress-strain relation for a linear material,

$$\sigma = (\lambda + 2\mu)(\epsilon - \epsilon * F)/(1 - f_0), \qquad \text{(Boltzmann)} \tag{4}$$

where the star $(*)$ indicates a convolution integral,

$$\epsilon(t) * F(t) = \int_0^t \epsilon(\tau) F(t - \tau) d\tau. \tag{5}$$

Equation (4) is by intuitive methods directly derivable from the superposition principle for linear physical systems. This application is usually attributed to Boltzmann (1876); a detailed discussion of the one-dimensionol case is given by Zener (1948, p. 48–59). The function $F(t)$ is a hereditary or memory function which gives the effect of a strain in producing residual stresses at later times. There is some justification for calling $F(t)$ the stress relaxation rate, and hence some writers express $F(t)$ as the time derivative of a function called the stress relaxation function.

The factor $(1-f_0)$ is introduced to preserve the meanings of the constants λ and μ for the static case. That is, if we apply a unit step of stress in equation (5), we expect the final value of strain to be $1/(\lambda+2\mu)$. This condition will exist if f_0 is chosen equal to $f(0)$, the value of $f(s)$, the Laplace transform of $F(t)$, at $s=0$. To verify this statement, solve for the final value of strain by Laplace transform methods, using the final value theorem in the form given by Gardner and Barnes (1942, p. 265). At the same time, we can see that the value $f_0=1$ is excluded, since it corresponds to models of the Maxwell type which creep indefinitely. Hence a restriction on the hereditary function $F(t)$ is that its Laplace

transform must take on a positive value less than unity (or a zero value) at the origin.

There are at least three other forms in which a stress-strain relation could be written in terms of a convolution integral and different memory functions. Gross (1947, 1948, 1953) has investigated in detail the formal equivalence of various representations, and has also indicated the necessity for providing for reasonable static behavior. We have chosen the form (4) with the hereditary function $F(t)$ because it explicitly sets out the static condition which we desire to impose, because it considers the hereditary effect of strain in producing later stresses, which seems to us the more natural order, and finally because it still allows the derivation of a wave equation, in terms of displacement, as in the elastic case.

The displacement wave equation is obtained in the usual manner by manipulating three simultaneous differential equations involving stress, strain, and displacement. One of these is the stress-strain relation, which we now take as equation (4). The other two are the geometric strain-displacement relation and Newton's second law of motion. For the simple case under consideration, a plane dilatational wave in the x-direction, these relations are

$$\epsilon = \partial U/\partial x \tag{6}$$

and

$$\partial\sigma/\partial x = \rho(\partial^2 U/\partial t^2), \tag{7}$$

where $U(x, t)$ is the component of displacement in the x-direction (the only non-zero component in this case) and ρ is the density of the material. Equation (6) is, of course, the linearized geometrical relation for small strains, and in (7) body forces other than inertia are neglected. Proceeding in the usual fashion, assuming ρ is constant and all the required differentiation is valid, we substitute (6) in (4), differentiate with respect to x, and substitute the result in (7), obtaining the displacement wave equation

$$\frac{\partial^2 U}{\partial x^2} - \frac{\partial^2 U}{\partial x^2} * F(t) = \frac{1 - f_0}{c_p{}^2} \frac{\partial^2 U}{\partial t^2}, \tag{8}$$

where c_p is the dilatational elastic velocity $\sqrt{(\lambda + 2\mu)/\rho}$.

Some extremely interesting properties of the memory function $F(t)$ can now be deduced by applying the Laplace transformation to this equation. Let $u(x, s)$ be the transform of $U(x, t)$, and as before let $f(s)$ be the transform of $F(t)$. Then Equation (8) transforms into

$$\frac{\partial^2 u}{\partial x^2}\left[1 - f(s)\right] = \frac{1 - f_0}{c_p{}^2} s^2 u, \tag{9}$$

a linear equation which is readily solvable for any given boundary condition. As a differential equation in the variables u and x, (9) is simplified by the introduc-

tion of the function $\gamma(s)$ defined by

$$\gamma(s) = \frac{s}{c_p}\left[\frac{1 - f_0}{1 - f(s)}\right]^{1/2}. \tag{10}$$

This function of the complex transform variable s is, of course, closely connected with the relations between attenuation and frequency, and phase shift and frequency. To examine this connection, first obtain the response of the material when the source of the wave is an impulse of stress (Laplace transform = 1) applied at $x = 0$ and $t = 0$. The boundary condition on the displacement transform $u(x, s)$ is then $\partial u(0, s)/\partial x = \gamma^2/\rho s^2$, and the solution of (9) is

$$u(x, s) = -(\gamma/\rho s^2) \exp(-\gamma x). \tag{11}$$

The magnitude and phase of the steady state solution for a sine wave input of stress at $x = 0$ are obtained from the real and imaginary parts of (11) evaluated at $s = i\omega$, where ω is then the radian frequency. The attenuation with distance (db/ft) and the phase shift with distance (deg/ft) are then directly proportional to $\alpha(\omega)$ and $\beta(\omega)$, the real and imaginary parts of $\gamma(i\omega)$,

$$\gamma(i\omega) = \alpha(\omega) + i\beta(\omega), \tag{12}$$

α and β being real functions of frequency. In the theoretical discussion and the calculations which follow, it will be convenient to deal with α in ft^{-1}, or, to emphasize that it appears in an exponent, in nepers/ft, and similarly it will be convenient to use rad/ft for β. Numerical values in these units are proportional to db/ft and deg/ft.

To examine the relations between α, β, and the memory function $F(t)$ in greater detail, the next step is to adopt a notation for the real and imaginary parts of $f(i\omega)$,

$$f(i\omega) = f_r(\omega) + if_i(\omega), \tag{13}$$

and solve Equation (10), with $s = i\omega$, for α and β as functions of f_r and f_i. In arranging the form of this solution, we keep in mind that for applications to seismology we are primarily interested in the behavior of α and β at low frequencies; hence we put the expressions for α and β in a form suitable for obtaining the asymptotic behavior as ω approaches zero:

$$\begin{matrix}\alpha(\text{upper sign}) \\ \beta(\text{lower sign})\end{matrix} = \frac{\omega}{c_p}\left[\frac{1}{2}\,\frac{1 - f_0}{1 - f_r}\,\frac{\left[1 + \left(\frac{f_i}{1 - f_r}\right)^2\right]^{1/2} \mp 1}{1 + \left(\frac{f_i}{1 - f_r}\right)^2}\right]^{1/2}. \tag{14}$$

Since $f(0) = f_0$ is real, $f_r(0) = f_0$ and $f_i(0) = 0$. As ω becomes small, the quantity $(1 - f_0)/(1 - f_r)$ approaches unity and the quantity $f_i/(1 - f_r)$ approaches zero. Hence we can approximate (14) for low frequencies by a power series expansion

in terms of $f_i/(1-f_r)$. We require only one term for α, and two terms for β, to show the behavior at low frequencies,

$$\alpha = \frac{\omega}{2c_p} \frac{|f_i|}{1-f_0},$$
$$\beta = \frac{\omega}{c_p}\left[1 - \frac{3}{8}\left(\frac{f_i}{1-f_r}\right)^2\right]. \tag{15}$$

From inspection of these equations, we can see that by choosing suitable functions $F(t)$ we can have a very wide latitude in producing expressions for α and β to match any set of experimental data. The variation is not entirely unrestricted, however, and we wish to point out two interesting limitations on these memory functions.

Such limitations are, in fact, the whole point of considering the problem in terms of memory functions and stress-strain relations. For applications our interest is likely to be in the behavior of α, and from this viewpoint we might start directly with equation (11), with $s=i\omega$, fitting arbitrary equations to data for α and β or handling these quantities in some other suitable manner. But to avoid wandering unintentionally into the realm of non-linear behavior, we believe it is necessary to refer on occasion to the basic property of the material, the stress-strain relation, and to use this to derive a wave equation in conjunction with the strain-displacement and dynamic equilibrium relations (6) and (7), which we may consider to be well established.

The first limitation we wish to point out is that for a linear material the memory function chosen cannot lead to an attenuation exponent which is precisely proportional to the first power of frequency. For this linear frequency dependence of α, it would be necessary in (15) that $f_i(\omega)$ be a constant, and since $f_i(0)=0$, we should have $f_i(\omega)$ identically zero. But then α itself would be identically zero, which contradicts our presumption. It thus appears that if we assume the simplest possible variation of attenuation with frequency, a linear relation, we have necessarily embarked upon the consideration of a non-linear theory of wave propagation. Further study of possible memory functions $F(t)$, however, suggests that a linear theory will permit attenuation at low frequency proportional to $\omega^{1\pm n}$, where n is arbitrarily small. Thus it appears that the introduction of a small complexity in analytical representations of attenuation-frequency relations may permit the use of a linear theory, which we expect will be simpler than any non-linear theory. Consideration of the basic stress-strain relation also guides us away from such representations as that used by Birch and Bancroft (1938*a*) in which an imaginary number is allowed to appear in the wave equation in the time domain (before substitution of exp $i\omega t$ to obtain the complex harmonic solution). This formulation leads to the desired result of α proportional to frequency (at all frequencies), but it does not seem to be subject to physical interpretation in terms of stress and strain.

The second limitation restricts the possible memory functions $F(t)$ into two broad groups in terms of the properties of their transforms $f(s)$. If the transform of the memory function is analytic, α is proportional to ω^2 or a higher even power of ω at low frequency. Non-analytic transforms of the memory function which exhibit a branch point at $s=0$ are also permissible. This type of function can lead to more complicated variation of α with frequency.

If $f(s)$ is analytic at the origin, it can be expanded in a power series in s,

$$f(s) = f_0 + f'(0)s + f''(0)s^2/2! + \cdots . \tag{16}$$

By putting $s=i\omega$ we obtain $f_i(\omega)=f'(0)\omega$, and substitution of this relation in (15) gives $\alpha=\omega^2 f'(0)/2c_p(1-f_0)$ for low frequencies. If it happens that $f'(0)$ is zero, then $f_i(\omega)$ becomes $i^{n-1}\omega^n f^{(n)}(0)/n!$, where n is the number of the first non-zero odd derivative of $f(s)$ at $s=0$, and then α becomes proportional to ω^{n+1}.

The Voigt model, or in general any relation such as (3) using higher order time derivatives of stress and strain, will lead to a rational function for $f(s)$. This function will not have a pole at $s=0$ provided we maintain the previously suggested condition that undifferentiated stress and strain terms appear explicitly with non-zero coefficients (actually for this argument it is only necessary that the stress term appear). Hence at low frequencies the attenuation in these cases will always turn out to be proportional to ω^2, or to some higher even power of ω.

To obtain some other variation of attenuation with frequency, it is necessary to use a memory function with a transform $f(s)$ which is not analytic at the origin. Since with the restrictions we have imposed $f(0)$ is confined to the range $0 \leqq f_0 < 1$, $f(s)$ does not have a pole or an essential singularity at $s=0$, and hence we may conclude that $f(s)$ must be a multivalued function having a branch point at $s=0$. This is an important consideration in experimenting with memory functions in an endeavor to produce a low-frequency relation with attenuation not proportional to frequency squared. Any number of the most bizarre analytic functions $f(s)$ may be attempted without achieving the desired result. The only example which we have available at this time is $f(s)=f_0 \exp(-k\sqrt{s})$, which leads to α proportional to $\omega^{3/2}$. This example suggests that there might be a set of memory functions with transforms $f(s)=f_0 \exp(-ks^n)$, with n between 0 and 1. If these memory functions exist, α can be proportional to ω^{1+n}. These memory functions $F(t)$ have never been studied as far as we know; presumably their existence could be demonstrated, and this might be sufficient since we are primarily interested in values of α and will not necessarily ever have any need to compute actual values of the original memory functions.

Thus memory functions $F(t)$ acceptable for a linear stress wave theory can be divided into two large groups: (1) functions with transforms $f(s)$ analytic at the origin, leading at low frequency to attenuation increasing with the square or some higher even power of frequency; and (2) functions with transforms $f(s)$ having a branch point at the origin, leading (at low frequency) to other variations of attenuation with frequency. All stress-strain relations making use of derivatives as in equation (3) fall in the first group. In neither group can there

exist memory functions leading to attenuation precisely proportional to frequency at low frequency, although we suspect that the power of frequency can be arbitrarily close to unity.

EXTENSION TO SHEAR WAVES AND THREE DIMENSIONS

As in the elastic case, the generalized three-dimensional stress-strain relations for a linear solid formulated by Boltzmann (1876) according to the superposition principle involve six independent stresses and six independent strains. A linear isotropic material requires two independent memory functions in addition to two elastic constants. These equations apparently have been explicitly set forth very infrequently, especially in English, and we repeat them here with three objects in view. First, we wish to arrange the notation so that the static elastic constants of Lamé, λ and μ, retain their usual meanings. Second, since these equations have not been so widely used as to establish the notation employed by previous writers, we wish to suggest a pair of symbols for the two basic memory functions. Third, we need to relate these basic functions to the memory functions $F(t)$ which we have already discussed in the one-dimensional case.

In the elastic theory the extension of the one-dimensional case (1) can be carried out in the following way. The nine stress components σ_{ij}, with i and j running from 1 to 3, are written as linear functions of the nine strain components ϵ_{ij} with 81 elastic constants. The condition of rotational equilibrium of arbitrarily small volumes leads to $\sigma_{ij}=\sigma_{ji}$, $\epsilon_{ij}=\epsilon_{ji}$, and the number of constants is reduced to 36. From the further assumption that the strain energy is a univalued function of the strain, the number of independent constants can be reduced to 21. Finally, for the simplest case of wide interest, an isotropic material, the condition that the equations must be invariant to a rotation of axes may be applied to reduce the number of constants to two, which may be taken as Lamé's constants λ and μ. For the general linear case involving the superposition or convolution integrals, these analyses can be carried out in a similar manner. Some of the details are given by V. Volterra (1909*a* and 1909*b*). The effect of this procedure is to replace λ and μ in the elastic equations by two operators, $\lambda(1-\Lambda^*)/(1-\lambda_0)$ and $\mu(1-G^*)/(1-g_0)$, where an operator $(1-M^*)$ applied to a function $H(t)$ is interpreted as $H-H*M$, the star as before indicating a convolution integral of the two functions. The functions $\Lambda(t)$ and $G(t)$ are the two basic memory functions for an isotropic solid. They are associated respectively with the elastic constants λ and μ. The constants λ_0 and g_0 are included, as in the one-dimensional case previously discussed, so that λ and μ will have the usual meanings for a static case and will be related in the usual way to Young's modulus and Poisson's ratio.

With this notation, the stress-strain relations for a linear isotropic solid, in general orthogonal curvilinear coordinates x_1, x_2, x_3, are as follows:

$$\sigma_{ii} = \lambda(\Delta - \Delta * \Lambda)/(1 - \lambda_0) + 2\mu(\epsilon_{ii} - \epsilon_{ii} * G)/(1 - g_0), \tag{17}$$

$$\sigma_{ij} = \mu(\epsilon_{ij} - \epsilon_{ij} * G)/(1 - g_0), \qquad i \neq j, \tag{18}$$

where Δ is the dilatation $\epsilon_{11}+\epsilon_{22}+\epsilon_{33}$. These equations can also be found, with a different notation for $\Lambda(t)$ and $G(t)$, in Boltzmann (1876), V. Volterra (1909*b*), Derjaguine (1934), and E. Volterra (1951). A wave equation in terms of the displacement vector $\mathbf{U}$ can be obtained by combining these stress-strain relations with strain-displacement relations and Newton's second law (these latter relations are generally available in textbooks). The operators mentioned above can also be substituted in the elastic displacement wave equation to obtain the same result,

$$\nabla\nabla\cdot\left[\lambda(\mathbf{U}-\mathbf{U}*\Lambda)/(1-\lambda_0)+2\mu(\mathbf{U}-\mathbf{U}*G)/(1-g_0)\right] \\ -\nabla\times\nabla\times\left[2\mu(\mathbf{U}-\mathbf{U}*G)/(1-g_0)\right]=\rho(\partial^2\mathbf{U}/\partial t^2). \tag{19}$$

This form suggests defining another memory function which is a combination of $\Lambda(t)$ and $G(t)$, just as in the elastic case the combination $\lambda+2\mu$ is conveniently treated as a single constant. We define a function $F(t)$ by the relation

$$\lambda(1-\Lambda)/(1-\lambda_0)+2\mu(1-G)/(1-g_0)=(\lambda+2\mu)(1-F)/(1-f_0), \tag{20}$$

from which it follows that

$$F(t)=\frac{\lambda}{\lambda+2\mu(1-\lambda_0)/(1-g_0)}\Lambda(t)+\frac{2\mu}{2\mu+\lambda(1-g_0)/(1-\lambda_0)}G(t), \tag{21}$$

$$f_0=\frac{\lambda\lambda_0}{\lambda+2\mu(1-\lambda_0)/(1-g_0)}+\frac{2\mu g_0}{2\mu+\lambda(1-g_0)/(1-\lambda_0)}. \tag{22}$$

The wave equation (19) can now be written in terms of $F(t)$ and $G(t)$ in a form which more closely resembles the elastic wave equation,

$$c_p^2\nabla\nabla\cdot(\mathbf{U}-\mathbf{U}*F)/(1-f_0)-c_s^2\nabla\times\nabla\times(\mathbf{U}-\mathbf{U}*G)/(1-g_0)=\partial^2\mathbf{U}/\partial t^2, \tag{23}$$

where c_s is the elastic shear wave velocity $\sqrt{\mu/\rho}$.

The significance of the function $F(t)$ is now apparent—it is the memory function for purely dilatational waves, or more generally for the irrotational part of any wave (corresponding to the vanishing of the curl curl term in 23). It is identical with the memory function $F(t)$ which appears in the discussion of the one-dimensional case.

STEADY STATE SPHERICAL DILATATIONAL STRAIN WAVES

For the analysis of a particular set of experimental data which will be described in a later section, a special solution of equation (19) was required under the simplifying assumptions of spherical symmetry, zero shear components, and harmonic or sine wave time variation. The absence of a shear wave will eliminate the second term (curl curl) of the left member of (19), and the condition of spherical symmetry will simplify the first term (grad div), since the radial displacement $U_r(r, t)$ is the only non-zero component of $\mathbf{U}$. The introduction of

harmonic time variation exp $i\omega t$ permits the convolution integral involving $F(t)$ to be expressed in terms of its Laplace transform $f(s)$ evaluated at $s = i\omega$. Equation (19) then reduces to a scalar equation for $u_r(r, i\omega)$, the magnitude and phase of the steady state radial displacement.

$$\frac{\partial^2 u_r}{\partial r^2} + \frac{2}{r}\frac{\partial u_r}{\partial r} + \frac{2}{r^2}u_r = \gamma^2(i\omega)u_r, \tag{24}$$

where γ is the function given by (10). While these operations are straightforward, they are not infrequently carried out incorrectly through misinterpretation of of the operator ∇^2 applied to a vector. The third term on the left of (24) is then omitted, as in Bullen (1953, p. 66).

This equation can be simplified by the adoption of a potential function ψ defined by $\mathbf{U} = \nabla(\psi/r)$. The solution can be found in standard references (for example, Kamke, 1948, p. 444, equation 2.170), and for a wave travelling in the r-direction it is

$$u_r(r, i\omega) = A\left(\frac{\gamma}{r} + \frac{1}{r^2}\right)e^{-\gamma r}, \tag{25}$$

where A is an arbitrary constant. In the experiment to be considered, the radial strain was measured. This quantity is obtained by differentiating (25) with respect to r,

$$\epsilon_{rr}(r, i\omega) = \frac{\partial u_r}{\partial r} = A\left(\frac{\gamma^2}{r} + \frac{2\gamma}{r^2} + \frac{2}{r^3}\right)e^{-\gamma r} = \frac{A}{r}G(\gamma, r)e^{-\gamma r}, \tag{26}$$

where

$$G(\gamma, r)/r = \gamma^2/r + 2\gamma/r^2 + 2/r^3 \tag{27}$$

is the geometric factor in the solution. In a boundary value problem, the constant A would be evaluated at some radius where the magnitude and phase of the wave were given. We wish to consider the changes in magnitude and phase between two radii r_1 and r_2. When we write the ratio of the radial strains at two different distances the constant A disappears and we have

$$\frac{\epsilon_{rr}(r_2, i\omega)}{\epsilon_{rr}(r_1, i\omega)} = \frac{r_1}{r_2}\frac{G(\gamma, r_2)}{G(\gamma, r_1)}\exp[-\gamma(r_2 - r_1)]. \tag{28}$$

Note that the propagation exponent $\gamma(i\omega)$ is also involved in the factor $G(\gamma, r)$ arising from the spherical geometry. In general, this situation increases the difficulty of separating the effect of geometrical divergence from the effect of energy dissipation. Simplifying approximations can be used with suitable combinations of sufficiently large distances and sufficiently high frequency; so far, however, we have not found any way to determine in advance the range of validity of such approximations.

METHOD FOR CALCULATION OF ATTENUATION VS. FREQUENCY

The strains in equation (28) are complex numbers whose magnitudes and angles give the magnitudes and phases of steady state strain waves of radian frequency ω at distances r_1 and r_2. Suppose that we have experimental data giving these magnitudes and phases at a number of different frequencies. We note that the manner in which the propagation function $\gamma(s)$ appears in (28), both in the exponential function and in the geometrical factor, is independent of the form of the dilatational memory function $F(t)$ appearing in the original stress-strain relation (17). Thus we can use the experimental data directly in (28) to solve for γ, and hence for the attenuation and phase shift coefficients α and β, as functions of frequency. After these are determined, we can in principle, if we wish, go further and ascertain the form of the memory function $F(t)$ in the time domain. As previously mentioned, however, we may not be interested in actually calculating $F(t)$; we may refer to it only for the purpose of imposing certain limitations on the form of equations used for fitting the experimentally determined curves of α and β against frequency. These restrictions are for the purpose of maintaining our assumption of linearity until we are forced to abandon it by the behavior of the data.

To calculate α and β at a single frequency, we express the experimentally determined strains, magnitude and phase, at two distances r_1 and r_2 as complex numbers and substitute these values on the left side of (28). Since the radii are known, we then have a single equation involving the unknown complex number γ. Alternatively, γ can be expressed in terms of its real and imaginary parts α and β. Equation (28) then separates into two simultaneous equations with these two unknown quantities. In either case, the unknown quantity or quantities appear both algebraically and within the argument of a transcendental function, so that the best procedure probably is to resort to a graphical or numerical solution. Any individual computer would, of course, be guided by his own knowledge and experience. We present a method which seems to us reasonably simple and sufficiently accurate to use with any data likely to be available. This procedure is to construct, for each pair of radii involved in the experimental data, a chart with ratios of strain magnitudes at r_1 and r_2 on the vertical axis and the phase difference between strains at r_1 and r_2 on the horizontal axis. Superimposed on the rectangular grid is a grid of curved lines corresponding to constant values of α and β. At any frequency, equation (28) is then solved by locating a point on the chart at the experimental values of strain magnitude ratio and strain phase difference. The corresponding values of α and β are read by interpolating between the superimposed lines of the curved grid. An example of such a chart is shown in Figure 5 for radial distances of 10 feet and $27\frac{1}{2}$ feet. It should be noted that the construction of the chart depends on the individual values of radii used, and not on their ratio only. As might be anticipated, the ratio of the radii is the dominant part of the geometrical factor over a considerable portion of the chart; the ratio of the functions $G(\gamma, r_1)$ and $G(\gamma, r_2)$ is close to unity, and equa-

tion (28) can be solved explicitly. It appeared difficult, however, to determine simple rules for setting off this portion of the chart in advance, since the location of a point on the chart is affected by frequency. Hence we have preferred in each case to construct a chart rather than rely on somewhat uncertain approximations.

The preceding discussion has referred to equation (28) as an example because the analysis of a set of strain wave records will be considered in the next section. If displacement measurements were made, equation (25) would be used in a similar manner, and if velocity or acceleration data were available the appropriate equation could be obtained by differentiating the displacement U_r once or twice with respect to time ($U_r = u_r \exp i\omega t$, where u_r is given by (25)).

BUREAU OF MINES STRAIN WAVE RECORDS

The data which we have analyzed by the foregoing method in an effort to determine attenuation (α) as a function of frequency for a particular material

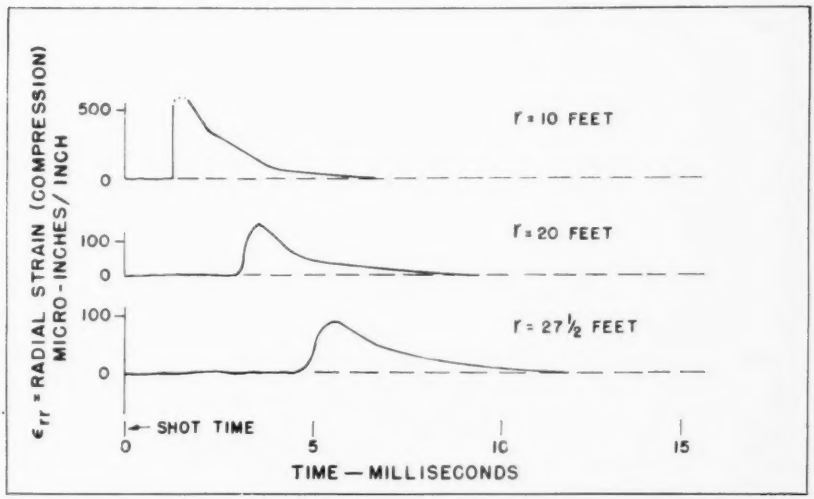

FIG. 2. Radial strain waves measured with resistance strain gages at three distances on a horizontal line from the charge nine inches below the surface. The Fourier analyses of these pulses (magnitudes and phases) are given in Figures 3 and 4.

were kindly supplied to us by Mr. Wilbur I. Duvall, Chief of the Mineral Mining Research Section of the U. S. Bureau of Mines laboratory at College Park, Maryland. These are the as yet unpublished records from one experiment in a very extensive research program, one of whose current objectives is the determination of the effect of explosives on the productivity of oil and gas wells. The results of this work are appearing in a series of reports (in the references,

see under Atchison, Blair, Duvall, Grant, Obert, and Windes). This particular test is identified, and will be listed in future Bureau of Mines reports, as shot No. 11, Eakin Quarry, series III, Kennerdell, Pennsylvania, November 1953, in a sandstone of the Pottsville formation, Homewood member. The charge was a cylinder of ammonia dynamite: diameter 0.46 ft, length 0.68 ft, weight 8 lb.

Records were taken from six gage holes on a horizontal line from the shot at distances of $2\frac{1}{2}$, 5, 10, 20, 25, and $27\frac{1}{2}$ feet. The detectors were resistance

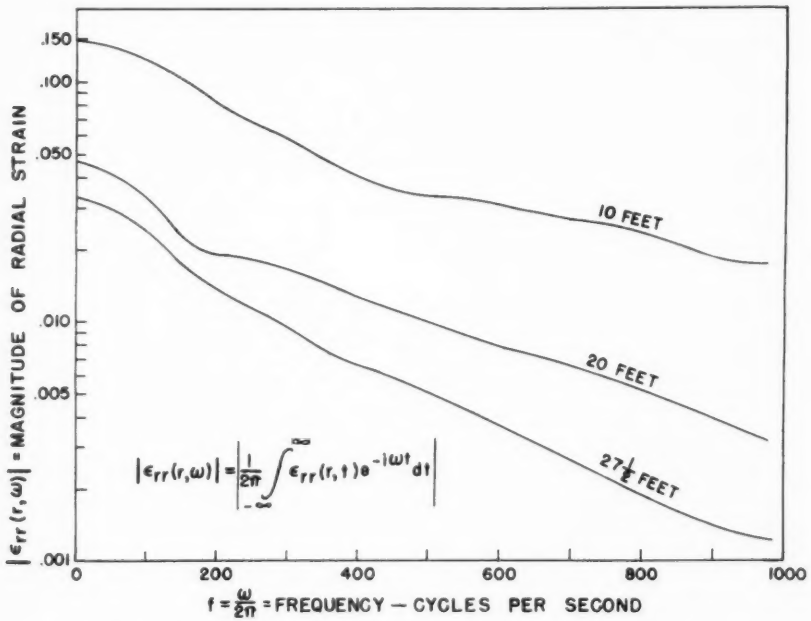

FIG. 3. Magnitude spectra—harmonic analyses of radial strain wave pulses shown in Figure 2. In conjunction with the phase spectra of Figure 4, these are treated as steady state sine wave data in calculating attenuation exponent α and phase shift coefficient β from Figure 5 and two other similar charts.

strain gages oriented to measure strain along a line from the shot. These gages were mounted on diamond drill cores from the gage holes—the precautions observed in this elaborate technique have been described by Obert and Duvall (1949). The recordings were made on 35 mm film mounted on a drum rotating at a speed such that the time scale was one millisecond per centimeter.

The principal parts of the records at 10, 20, and $27\frac{1}{2}$ feet are shown in Figure 2. The film strips were actually over 2 feet long and the duration of the records 67 milliseconds. Following the principal parts shown, the records consisted of

slowly oscillating tails of very small amplitude. These long tails were not considered in the analysis—as indicated in Figure 1, the records were treated as though the curves and their slopes became zero at the end of the first positive section.

While analyses were actually made of all six records at the six distances, the results from the three records at 10, 20, and 27½ feet are thought to be more significant. The strains recorded at 2½ feet and 5 feet are very probably beyond any possible linear range. The records show evidence of a permanent strain, and the peak strains recorded are far up on the non-linear portion of the static stress-

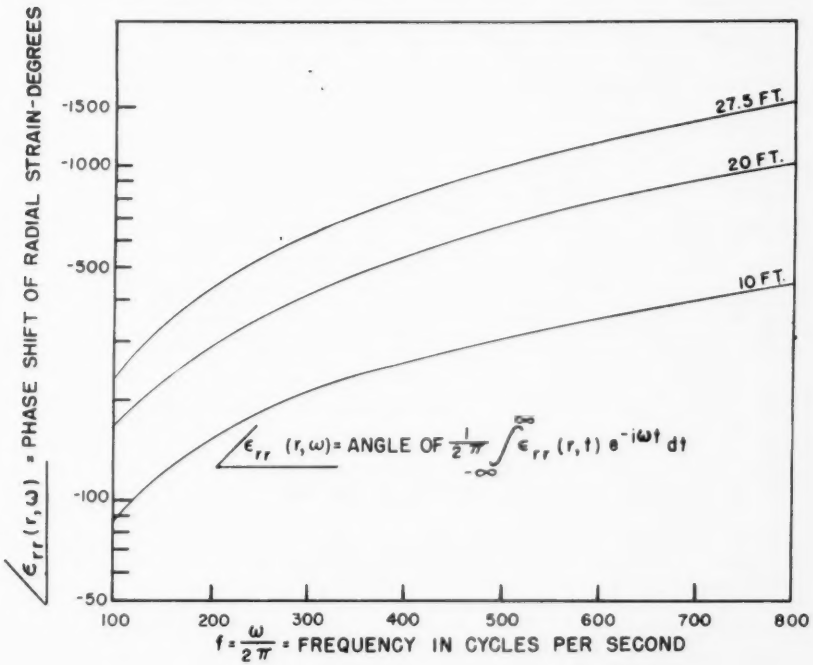

FIG. 4. Phase spectra corresponding to the magnitude spectra of Figure 3.

strain curve for samples of the rock. The record at 25 feet was considered possibly anomalous because the peak strain did not fall on the curve of peak strains versus distance. The deviation is not more than is frequently observed in these experiments, but since the other curves did show a good correlation of peak strains, the record at 25 feet was considered to be less consistent than the remainder of the data.

We then consider the three curves of Figure 2 and use them as a basis for calculating attenuation versus frequency by the method previously described.

The first step is to convert the pulses to equivalent steady state sine wave data. There is a considerable literature on graphical and mechanical harmonic analysis. We used the trapezoidal rule of numerical integration, reading from 60 to 240 ordinates from each curve. In some cases rechecks were made to see if doubling the number of ordinates would make significant changes in the frequency spectrum.

The results of these harmonic analyses (magnitudes and phases of the Fourier integral) are shown in Figures 3 and 4. The magnitude spectra show some unexpected irregularities which we cannot account for. The possibility must be admitted that these result from the arbitrary termination of the curves and the

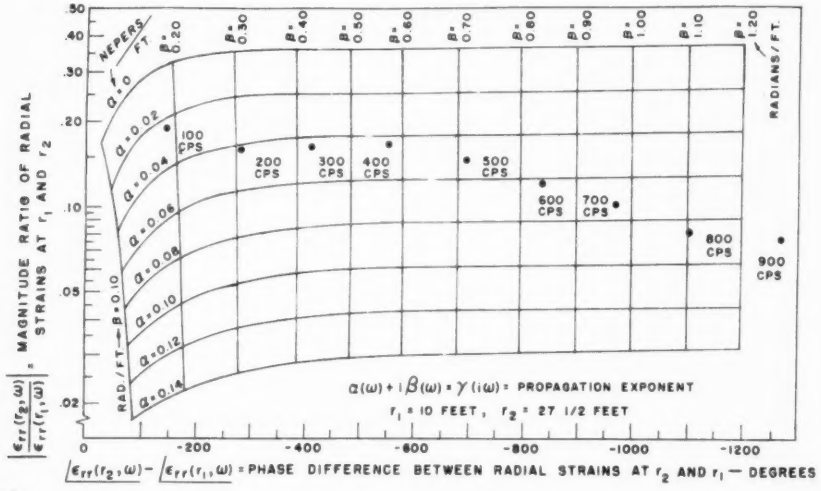

FIG. 5. Chart for calculation of propagation exponent. Prepared from Equation (28) for steady state spherically symmetrical dilatational strain waves in an isotropic solid. The points marked with frequencies from 100 to 900 cycles are located by taking magnitude ratios and phase differences from the frequency spectra at 10 feet and 27½ feet in Figures 3 and 4. Values of the propagation exponent α and the phase shift coefficient β are obtained by interpolating in the grid of curved lines. A separate chart is needed for each pair of radial distances.

neglect of the long oscillating tails. Our original estimate was that it would be safe to terminate the curves at points where the ordinates and derivatives were both zero. The phase shift curves are very regular but this result might be anticipated even under very difficult circumstances. The attenuation will be small, and hence in a linear material we expect the dispersion, or variation of phase velocity v with frequency, to be negligible. The phase shift coefficient $\beta(=\omega/v)$ is then substantially proportional to frequency. Any small deviations from linearity of β will be lost in the total phase shift which is substantially proportional to distance at large distances (there is a spherical geometric effect near the shot). Thus the phase curves are likely to be smooth despite the irregularities in the amplitude curves.

The harmonic analyses in Figures 3 and 4 are now treated as though they were steady state sine wave data, magnitude and phase, obtained with a spherical sine wave generator in an infinite medium. There are three pairs of radii, and for each pair we calculate α and β as functions of frequency using equation (24) for spherical dilatational harmonic strain waves. At any frequency, we express the ratio of strains as a complex number and solve for α and β using the charts previ-

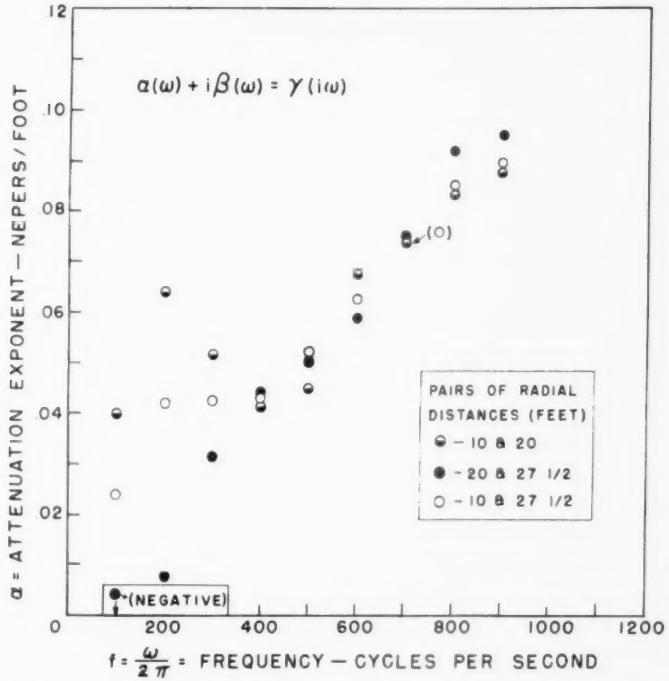

FIG. 6. Attenuation exponent vs. frequency. Calculated with Figure 5 and two similar charts for the other two pairs of radial distances, using the harmonic analyses of Figures 3 and 4. For definite conclusions to be drawn, the points from all three pairs of radii should lie close to a single smooth curve.

ously described. The chart for radii 10 and $27\frac{1}{2}$ feet is shown in Figure 5. The strain ratios are plotted at a number of frequencies, showing the location of the values of α and β on the network of curved lines. The calculated values of α and β for all three pairs of radii are plotted in Figures 6 and 7. Ideally, all points from the three pairs of radii should lie on a single smooth curve. Actually, we hoped that the points would be grouped well enough so that an average curve could be drawn. With the scatter of points which appears in Figures 6 and 7, however, it does not seem possible to reach a definite conclusion on the variation of α and β with frequency. Very roughly, α appears to increase more like the first

power of frequency than the square of frequency. Curves corresponding to many different equations could be drawn among these points, however, without being definitely inconsistent with the data. The phase shift coefficient β appears proportional to frequency, but as previously mentioned, we expect this result to a close approximation, regardless of the behavior of α.

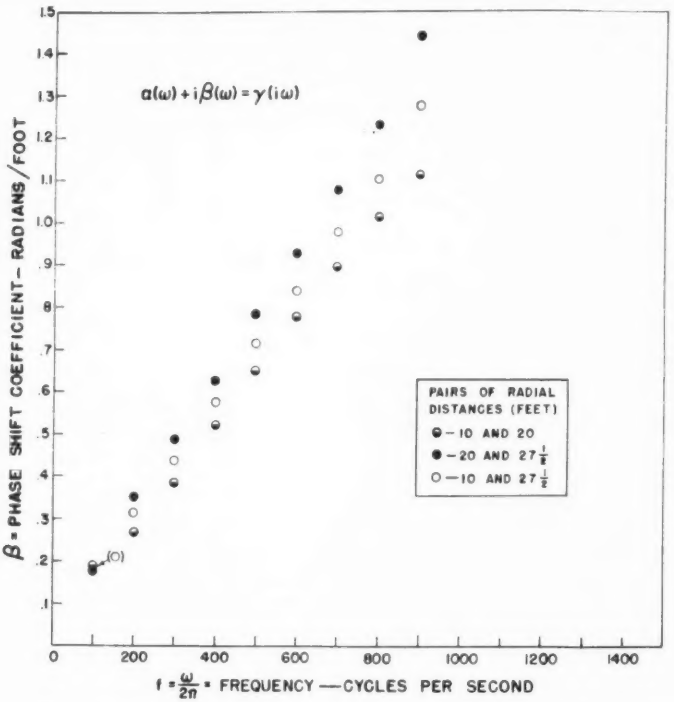

FIG. 7. Phase shift coefficient vs. frequency. Obtained in the same calculation as attenuation exponent, Figure 6. The grouping of points for different pairs of transmission distances is better than on the attenuation plot, particularly at the lower frequencies. We expect the phase shift coefficient to be substantially proportional to frequency for low frequencies and small attenuation regardless of the variation of attenuation. The calculated points are reasonably consistent with this expectation.

In looking for possible causes of the disappointing scatter of the plotted results, we must mention one experimental condition which may invalidate the assumption of spherical waves, and that is that the shot and the horizontal line, of gages were located only 9 inches below the surface. Under these conditions we would have expected a complicated wave containing components due to reflected waves and surface waves. The cleanness and apparent homogeneity of the wave forms, however, led us to believe that the records consisted entirely of directly travelling dilatational waves. Supporting evidence for this conclusion

came from the records taken on a line from the shot thirty degrees below the horizontal. These waves did appear to be composed of more than one arrival, and hence we did not attempt to analyze them. By contrast the wave shapes on the horizontal line appeared beautifully clean. Furthermore, a plot of first arrival times versus radial distance from the shot point at the horizontal and 30-degree detectors formed a single smooth curve suggesting that they were waves of the same type, and for the wave on the 30-degree line it seemed reasonabe to suppose that the first arrival indication would be due to the dilatational wave. There remains the possibility of re-analyzing the data using a more complex mathematical procedure to take into account the actual geometry of the situation. We would then, however, again be faced with the problem of assuming the size and shape of some source volume around the shot at which behavior becomes linear, and this is one of the problems we are most anxious to avoid.

It is also possible that even from 10 to $27\frac{1}{2}$ feet from the shot the behavior is still non-linear. The peak strains at the three distances studied were 590, 155, and 90 microinches/inch, and the lowest of these is several times as high as we need to consider in seismology.

We had previously attempted to obtain records similar to these at more interesting conditions of pressure, temperature, and water saturation by propagating waves horizontally in strata at depths of 70 feet and 200 feet. We were unable to obtain clean waves which were not marred by overlapping arrivals. Hence we were interested in studying these extremely clean records taken by the Bureau of Mines, since they at least were free from the worst of our former difficulties. Despite the inconclusiveness of these results, we feel that this method still offers the best possibility for determining attenuation versus frequency, and hence of determining the propagation equation of stress waves in an inelastic earth. We are planning additional experiments which we hope to analyze in a similar manner.

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GEOPHYSICS, VOL. XXI, NO. 1 (JANUARY, 1956), PP. 41-70, 19 FIGS.

ELASTIC WAVE VELOCITIES IN HETEROGENEOUS AND POROUS MEDIA*

M. R. J. WYLLIE,† A. R. GREGORY,† AND L. W. GARDNER†

ABSTRACT

Longitudinal wave velocities in numerous synthetic and natural porous media at room temperature and pressure have been measured. Basic characteristics of the measuring device are briefly described. Wave velocities have been found for aggregates of uniform spheres of various diameters both when dry and when saturated with water, brine, organic liquids and plastics. The effect of porosity on the wave velocity through aggregates of glass spheres saturated with plastic has been determined over the porosity range 19%-70%. Experimental measurements have been made of the effect of varying brine-oil and brine-gas saturations on the wave velocity through natural sedimentary rock samples. The effect of salinity and temperature on the wave velocity through sodium chloride brines has been redetermined.

Results are graphically presented to show experimental relationships between wave velocity, porosity, pore content and matrix nature of sedimentary rocks. Some conclusions are drawn regarding general relationships between these factors based on the experimental results and on theoretical considerations. Through these relationships continuous velocity logs in wells can be interpreted to furnish a measure of formation porosity. Some comparisons are given between porosities derived from continuous velocity logs and found by core analysis.

INTRODUCTION

An ultrasonic velocity meter which readily measures the propagation velocity of high-frequency pulses through hand samples of materials has been designed and built at the Gulf Research Laboratory. It has been used to acquire experimental data on the velocities of a variety of substances under different conditions, emphasis being placed on porous granular media.

The pulse technique for measuring velocities, which is embodied in the meter, was pioneered by Hughes and his co-workers. (Hughes, Pondrom, and Mims, 1948; Hughes and Jones, 1950; Hughes and Cross, 1951.) These workers have also made rather penetrating investigations of the influence of such factors as pressure, temperature, porosity and saturation upon numerous samples of differing kinds of rocks. We have some measurements on rocks as well as on synthetic porous media.

The bulk of the data presented refers to measurements carried out on synthetic and natural porous media unsubjected to heavy confining or compacting pressures. In general, no difficulty has been encountered in making such measurements. The fact that the velocity of sound in air itself can be readily obtained shows the efficacy of the measuring device.

Considerable attention has also been paid to the analyses of continuous velocity logs in terms of porosity.

* Presented before the Society at its New York meeting March 30, 1955. Manuscript received by the Editor May 31, 1955.

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APPARATUS

Figure 1 is a picture of the velocity meter which was designed and built by the Geophysical Development Division, J. L. Mundy being primarily responsible for design and constructional details. A sample of material to be measured is

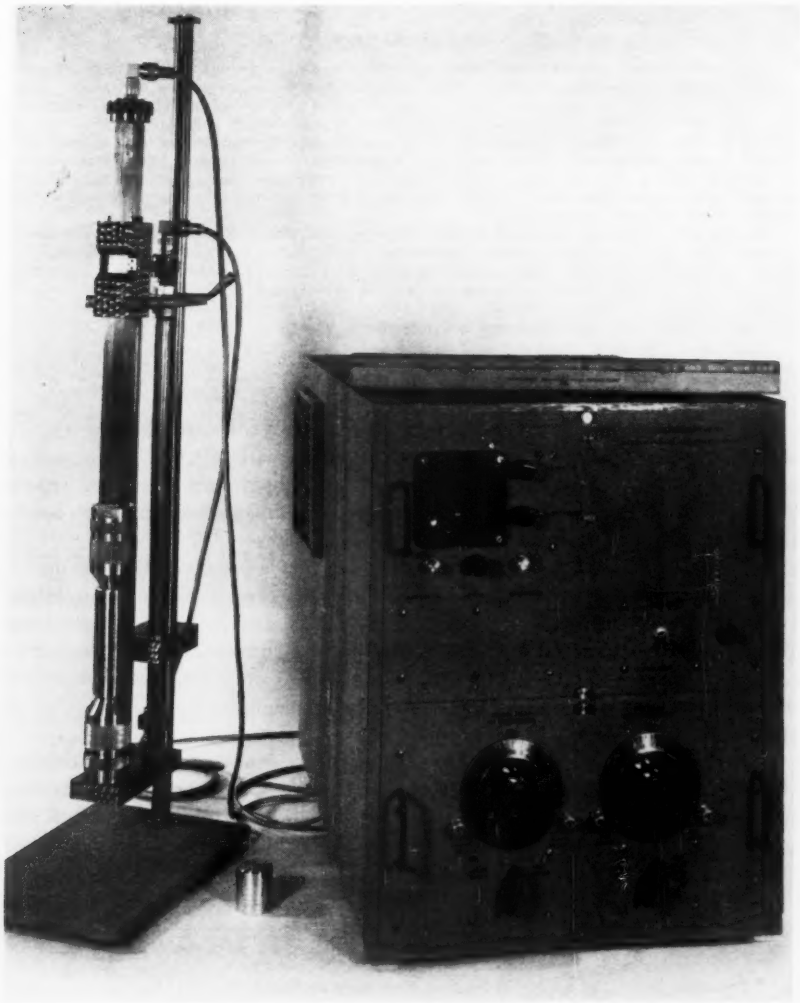

FIG. 1. Ultra sonic velocity meter and sample holder.

placed in the sample holder between the two heads. Each head contains a piezoelectric crystal (barium titanate), one of which acts as a source of repeated sound pulses and the other as a receiver of the pulses after transmission through the sample. Two representative signals are displayed on the oscilloscope, Figure 2. One corresponds to the output pulse and the other is a reference or time measuring pulse generated by the input pulse, but which is delayed in the elec-

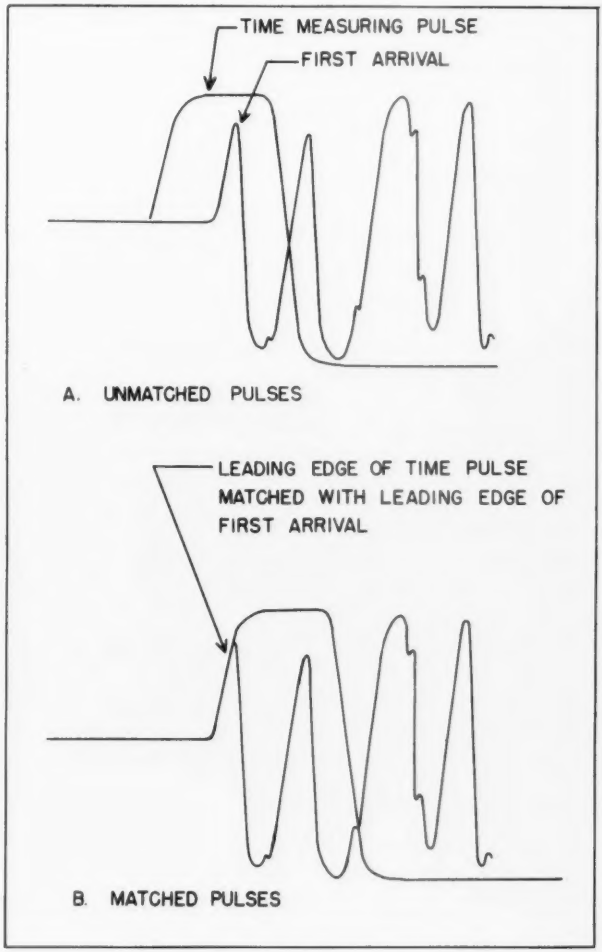

FIG. 2. Arrivals through brass as displayed on oscilloscope.

trical circuits by an interval of time which is adjustable and measurable with the dials on the front of the case. For measuring any given sample the dials normally are adjusted until the two pulses representative of input and output are superimposed. The horizontal displacement on the oscilloscope, however, also furnishes a measure of time variations between the two pulses and of the frequencies present in the output signal. Other controls on the instrument permit adjustment of the gain of the output signal, switching to a different horizontal time scale on the oscilloscope and different time intervals between repeated input pulses.

The nature of the measurements is such that the velocity measured is that of the first significantly strong energy to pass through the sample. Accordingly, it is the longitudinal wave velocity that is obtained.

The principal frequency components of the observed pulses in the present experiments range between 200 and 1,000 kilocycles; in general, they are about one-tenth the magnitude of those used by Hughes. Corresponding wave lengths of the transmitted signals range between 0.1 and 1 inch, being smaller than, but sometimes approaching, the diameter of specimens; in general, the wave lengths are large compared with grain or pore sizes. No change in velocity was observed upon changing the crystal with associated change in the frequency components of the transmitted signal. None of the measurements that have been made shows any appreciable dependence on frequency.

Many of the measurements that have been made have been repeated, some of them a number of times. A particular cylinder of brass has been frequently measured; indeed it serves as a standard to demonstrate that the instrument is always giving true readings. For all of the velocity measurements, transit time determinations could be repeated at will to within about 0.1 microsecond for total transit times ranging from a minimum of 6 microseconds to a maximum of 270 microseconds. Since the travel distance between the heads is determined rather precisely by means of a scale on the specimen holder, the velocity measurements usually are reliable to within about $\pm 1\%$.

The measured velocities of a number of metal cylinders are: Aluminum—21,550 ft/sec; brass—14,150 ft/sec; lead—7,300 ft/sec; and steel—17,600 ft/sec. Velocities of brines have been measured under a variety of conditions with results to be shown later.

RESULTS

Velocities of Miscellaneous Solids and Liquids

The results of measurements of a number of typical rock types are shown in Table 1. Many of these rocks are crystalline in nature and have strongly anisotropic properties. The two velocities recorded are those along two different axes of the sample (not necessarily along crystal axes except in the cases of calcite and quartz). These measurements were made at atmospheric pressure and at a temperature of about 25°C. Obviously, these velocities merely exemplify typical

TABLE I

MINERAL VELOCITIES AT ROOM TEMPERATURE AND PRESSURE

Mineral	Observed Directional Velocity (ft./sec.)		
	X	*Y*	*Z*
Anhydrite ($CaSO_4$)	20,340	20,790	20,360
Barium Titanate	15,700	—	—
Calcite ($CaCO_3$)	23,060	21,570	15,740
Dolomite ($CaCO_3 \cdot MgCO_3$)	14,960	—	—
Feldspar ($K_2O \cdot Al_2O_3 \cdot 6SiO_2$)	12,150	18,760	12,460
Feldspar ($Na_2O \cdot Al_2O_3 \cdot 6SiO_2$)	14,370	21,920	—
Gypsum ($CaSO_4 \cdot 2H_2O$)	18,970	17,460	21,300
Halite (Rock Salt)	15,350	—	—
Mica Schist	5,000	16,650	12,860
Opal ($SiO_2 \cdot H_2O$)	17,250	—	—
Quartz	17,650	17,750	21,400
Slate	16,230	20,600	—

Quartz and Calcite measured on crystal axes.

rock velocities, specific values being dependent not only on actual rock composition but on pressure, temperature, porosity, cementation, saturating fluids and direction in case of anisotropy. We are endeavoring to learn something more concerning the influence of these factors.

The measured velocities of a number of materials of particular interest, because of their use in experimental investigations, are shown in Table II.

The velocities of a number of liquids are shown in Table III.

Velocity of NaCl Brines as a Function of Concentration and Temperature

Figure 3 summarizes the data obtained; these considerably extend previously reported measurements. In all cases both crystal heads of the specimen holder were immersed in the brine being measured. Measurements were made over a path length of 6 to 8 inches. The sodium chloride used was of analytical grade and the water was distilled. The container was a rectangular copper box $4\frac{1}{2}'' \times 7'' \times 12''$.

TABLE II

VELOCITIES (ft./sec.) OF MISCELLANEOUS SOLIDS

Alundum Core	20,600
Cork Rod	2,650
Cork Sheet (5/16″ thick)	1,850
Glass Rod	17,850
Lucite	8,700
Nylon	8,650
Oil Stone	16,750
Paraffin Wax	6,900
Synthane	9,750
Selectron	8,000
Teflon	4,400

TABLE III

VELOCITIES (FT./SEC.) OF FLUIDS

Chloroform (26.2°C.)	3,200
Carbon Tetrachloride (26.6°C.)	3,000
Drilling Mud (26°C.)	4,870
Drilling Mud Cake	4,980
Distilled Water (25°C.)	4,912
Glycerol 100% (25°C.)	6,380
n-Hexane (26.2°C.)	3,511
n-Pentane (26.2°C.)	3,303
Silicone DC 200 Vis. 1 cs (29.2°C.)	2,900
Silicone DC 200 Vis. 0.65 cs (28.6°C.)	2,875
Ethyl Alcohol 95% (26°C.)	4,006
Absolute Ethyl Alcohol (26°C.)	3,815
Isopropyl Alcohol (26°C.)	3,744
Iso-Octane (26°C.)	3,622

There is excellent agreement between our results and those of Smith and Lawson (1954) and Barthel (1954) whose measurements were made with 12 and 15 megacycles/second waves respectively. The results also agree within

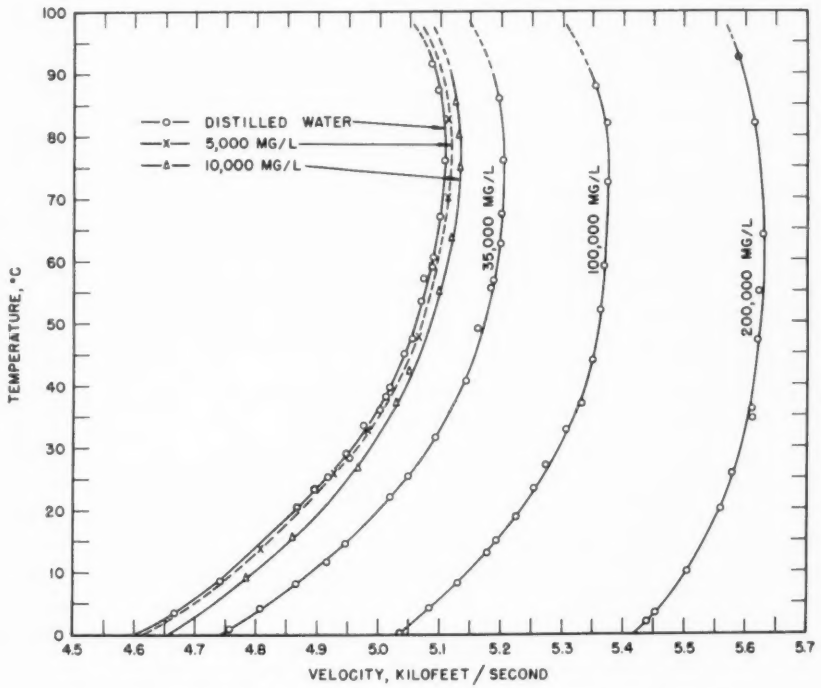

FIG. 3. Velocity as a function of brine temperature at various concentrations of NaCl.

about 1% with those of Dyk and Swainson (1953) in sea water although these workers used frequencies one thousandfold smaller. Accordingly, dispersion for sea water evidently is negligible over a wide range of frequencies.

Velocity Through a Lucite-Aluminum Pile

Aluminum discs of $1\frac{7}{8}$ inches diameter with thicknesses varying from $\frac{1}{8}$ inch to $\frac{1}{2}$ inch were set parallel to one another in Lucite so as to form a pile of alternating Lucite and aluminum segments. While setting the Lucite, heat and pressure were applied to eliminate air bubbles and to improve acoustic coupling. The Lucite layers varied in thickness from 1/16 to $\frac{1}{2}$ inch. Each pile so formed was designated by a porosity, this porosity being the fractional length of Lucite in the total length measured along the axis of the pile. Velocity measurements were made on piles covering a porosity range of 17 to 66%. The results are shown on Figure 4 together with a time-average velocity curve which is based on the summation of travel times in aluminum and Lucite (aluminum—20,800 ft/sec; Lucite—8,700 ft/sec), i.e.,

$$\frac{1}{\overline{V}} = \frac{\phi}{V_{\text{Lucite}}} + \frac{1-\phi}{V_{\text{Al}}} \qquad (1)$$

ϕ = porosity

$\overline{V}$ = time-average velocity

For such a system the theoretical velocity is the time-average velocity if the wave travel is directly through the pile normal to the discs whether wave lengths are large or small compared with the thicknesses of the segments. This follows from the fact that wave velocities and transmission coefficients are independent of frequencies for elastic media when there is no slippage or separation of interfaces. The agreement between the observed and time-average velocities is within the accuracy of the measurements and supports the above theoretical conditions.

Velocity Through Pile of Glass Plates

A multiplicity of glass microscope slides were stacked in a pile. Velocities measured along the length and breadth of a pile agreed with similar measurements for a single slide at about 17,530 ft/sec. Velocity measured across a pile of 50 slides gave a value of only 1,650 ft/sec. Across 25 slides the velocity was not much higher, and was very much higher only when the number of slides was reduced to a very few. With only two or three slides the velocity was of the order of 8,000 ft/sec., being poorly determinate. For all of these observations the transmitted frequencies as observed were many fold less than normal. The results were not changed materially by the application of some manual pressure to the heads of the specimen holder. When the faces of the slides were wet before being assembled into a pile, a true value of velocity for the glass was obtained, normal signal frequencies being observed. This experiment confirms the suspicion that poor coupling or cracks in materials can cause great decreases in velocities.

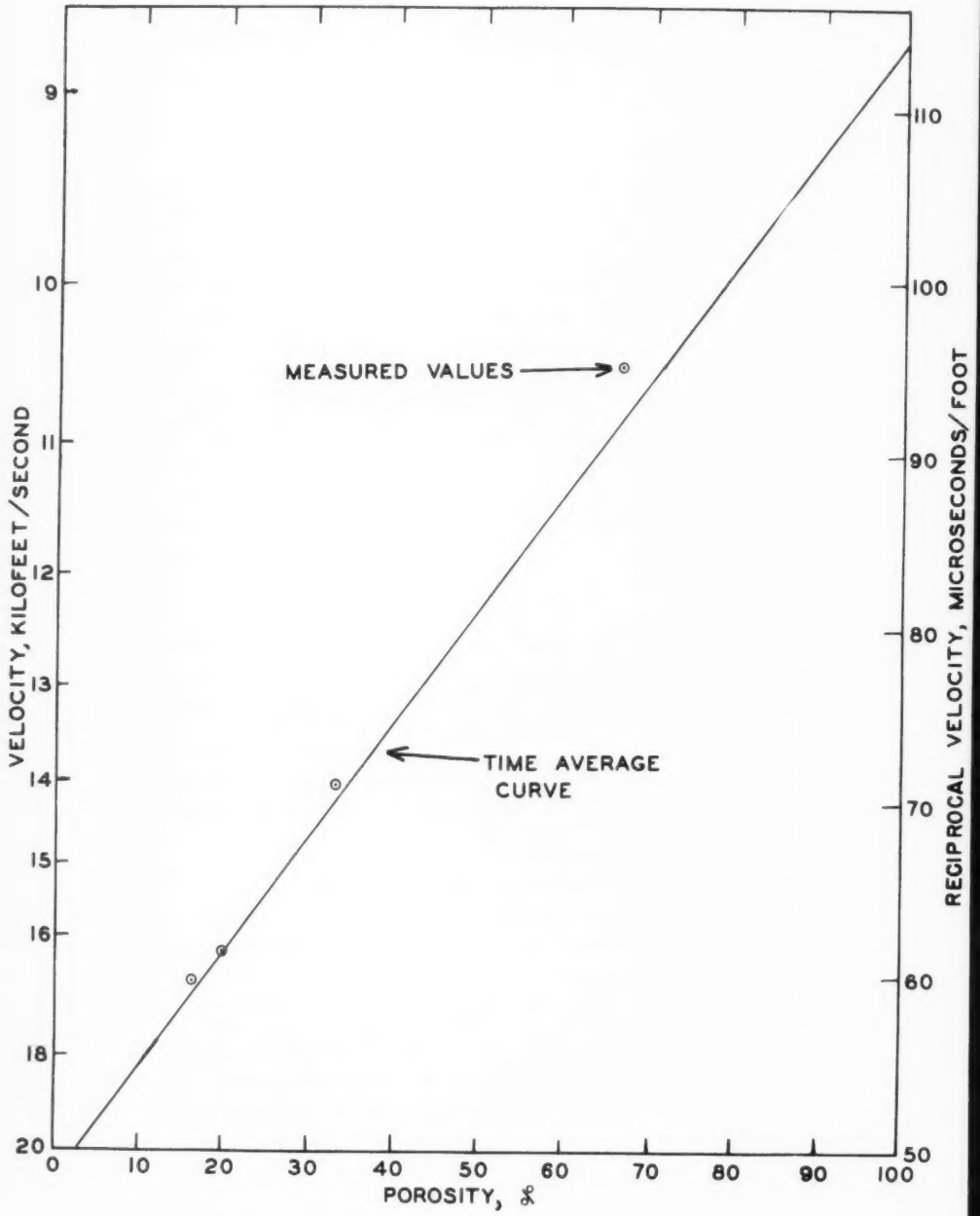

FIG. 4. Aluminum discs in lucite.

Velocity of Spheres Saturated with Fluids

Aggregates of spheres of uniform size, with packing intended to be random (porosity—38%), were saturated with various liquids and velocities measured. Similar measurements were made on dry aggregates, i.e. saturated with air.

The measurements were carried out in cork-walled boxes of square section (3″×3″). The bases of the boxes were of Lucite and the travel times through the bases were determined and subtracted from those obtained in an experiment. In all cases the upper crystal head was so supported that it applied only a negligible compacting pressure to the aggregate under investigation. No difficulties were encountered suggestive of energy being carried by the cork walls of the boxes.

The glass spheres used were those previously described in detail by Wyllie and Gregory (1955) in another connection. The lead spheres were obtained from the National Lead Company and were sized by sieving. The polystyrene spheres were made available by courtesy of the Cyanamid Fellowship of the Mellon Institute of Pittsburgh and were also sized by sieving and elutriation. All organic liquids used were of reagent grade; these liquids, the distilled water and the brines employed to saturate specimens were deaerated before use.

In the case of dry specimens the arrivals measured were generally poor, the output signal being of relatively very low frequency. The results obtained are of doubtful significance. On Figure 5 the scatter of points obtained for measurements made on dry glass spheres is evident.

In the case of aggregates of spheres saturated with liquids, the quality of the arrivals varied from good to excellent depending upon the saturating liquids used. A controlling factor, however, was the length of specimen, the maximum length over which energy could be detected with certainty being about 10 inches.

In Figure 5 the experimental points are plotted with the ratio Length of Specimen/Diameter of Sphere as ordinate and velocity as abscissa. This method of plotting rationalizes results which, when they were first obtained, appeared to be inconsistent and confusing. Our previous experience with aggregates of uniform spheres had indicated that flat surfaces often affect their random arrangement over a distance of numerous sphere diameters from the surface. In spite of this we were hardly prepared for the magnitude of the influence that two flat surfaces exert on the velocity of elastic waves through an aggregate of uniform spheres. As shown by Figure 5 a Length/Diameter ratio of at least 100 and preferably 1,000 is required before end effects become negligible. That the results shown on Figure 5 are indeed the consequence of an ordering of the packing (i.e. anisotropy) caused by the flat bottom of the container used and the flat head of the upper crystal holder is best seen from the fact that the velocity measured extrapolates to that of the sphere material when the Length/Diameter ratio is unity, i.e., when the velocity of a single sphere is measured.

An interesting conclusion stems from the fact that all data for uniform spheres fall on a common curve irrespective of sphere size. The porosity and type

REGIPROCAL VELOCITY, MICROSECONDS/FOOT

of packing of randomly disposed aggregates of uniform spheres are always identical and independent of sphere size. The permeability of such aggregates is, however, inversely proportional to their (surface area)^2 and thus the square of the diameter of the spheres composing them. Over the size range of the glass spheres

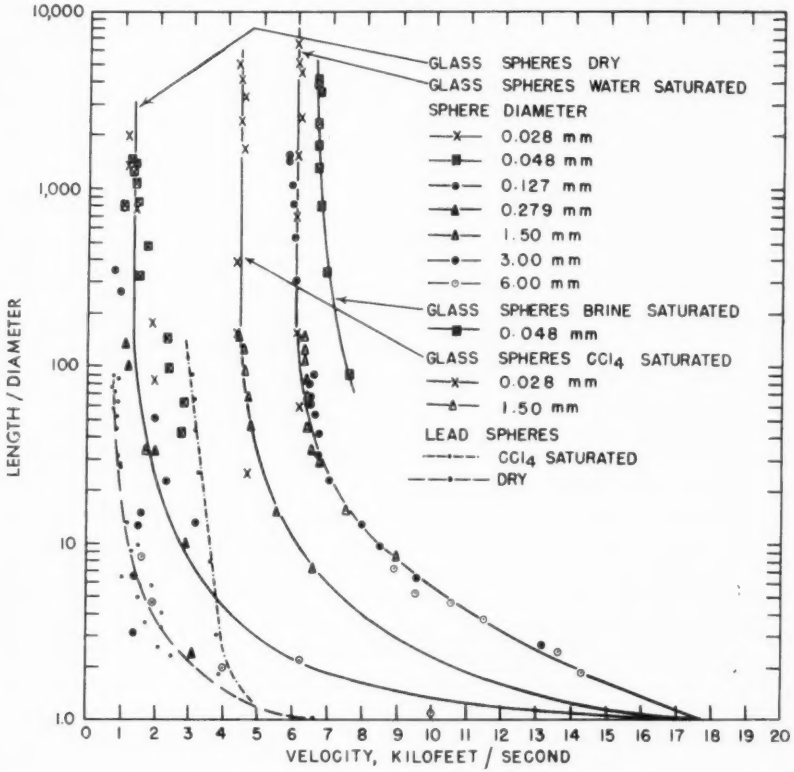

FIG. 5. Velocity as a function of aggregate length/particle diameter for unconsolidated aggregates of spheres.

used (6.00 mm to 0.028 mm), the permeability alters by a factor of 4.6×10^4 but the velocity is unaffected.

The data for spheres of 0.028 mm diameter saturated with water and carbon tetrachloride show that, provided a ratio Length of Specimen/Diameter of Sphere exceeding about 100 is used (thus obviating end effects), the velocity through a saturated aggregate is essentially constant. If anything, velocity decreases slightly with increasing specimen length; there is no evidence of the reverse effect occurring.

Table IV summarizes the results depicted by Figure 5. In Table IV velocity determinations for the various saturated aggregates are given for the condition that end effects are absent. Column 5 shows experimental values. Column 6 shows comparative values calculated to give the time-average velocity according to Equation (1). Column 7 shows comparative velocity values calculated from the formula

$$\frac{1 + q^*}{(V^*)^2} = \left[\frac{\phi}{V_1^2\rho_1} + \frac{(1 + q_s)(1 - \phi)}{V_s^2\rho_s}\right][\phi\rho_1 + (1 - \phi)\rho_s] \qquad (2)$$

in which ϕ designates the fractional porosity and V and ρ represent the velocity and density of the solid and liquid constituents with subscripts s and 1, respec-

TABLE IV

VELOCITY IN SATURATED AGGREGATES OF SPHERES AT ROOM TEMPERATURE AND PRESSURE (POROSITY 40%)

Solid	Fluid			Aggregate Velocities (ft/sec)		
Spheres	Nature	Density gm/cc	Velocity ft/sec	Observed	Time Average	Wood Formula
Glass	Brine	1.14	5,600	6,600	9,550	6,630
Glass	Water	1.00	4,820	6,080	8,600	5,600
Glass	C_2H_5OH	0.79	3,800	4,550	7,210	3,980
Glass	CCl_4	1.50	3,000	4,300	6,000	4,010
Glass	Oil	0.75	3,990	4,010	7,480	4,090
Glass	Silicone	0.76	2,870	3,620	5,800	2,980
Glass	Air	0.0013	1,130	1,300	—	—
Plastic	Water	1.00	4,820	5,500	6,550	6,130
	Solid					
Glass	Methyl Methacrylate	1.17	8,600	12,600	12,520	9,840

Glass Velocity 18,000 ft/sec, Density 2.40 g/cc.
Plastic Velocity 8,700 ft/sec, Density 1.17 g/cc.

tively. The asterisk* designates the system as a whole; q is related to the rigidity modulus. The derivation of Equation (2) together with more detail concerning the significance of q is given below. For the computation of data given in Column 7 of Table IV, q_s has been taken as 0.6, q^* as zero for liquid-saturated systems and 0.6 for the solid-saturated (methyl methacrylate) system. There is fair agreement between the measured velocities shown in Figure 5 and those calculated.

Velocity of Glass Spheres Saturated with Methyl Methacrylate

Aggregates of glass spheres were saturated with methyl methacrylate monomer and the monomer then polymerized under heat and pressure using a Buhler hydraulic press. This technique was evolved to avoid imperfections arising with thermosetting plastics. Separate experiments carried out on the pure monomer showed that the velocity of the polymer was insensitive to the method used for polymerizing the monomer. The velocity of the polymerized monomer was also

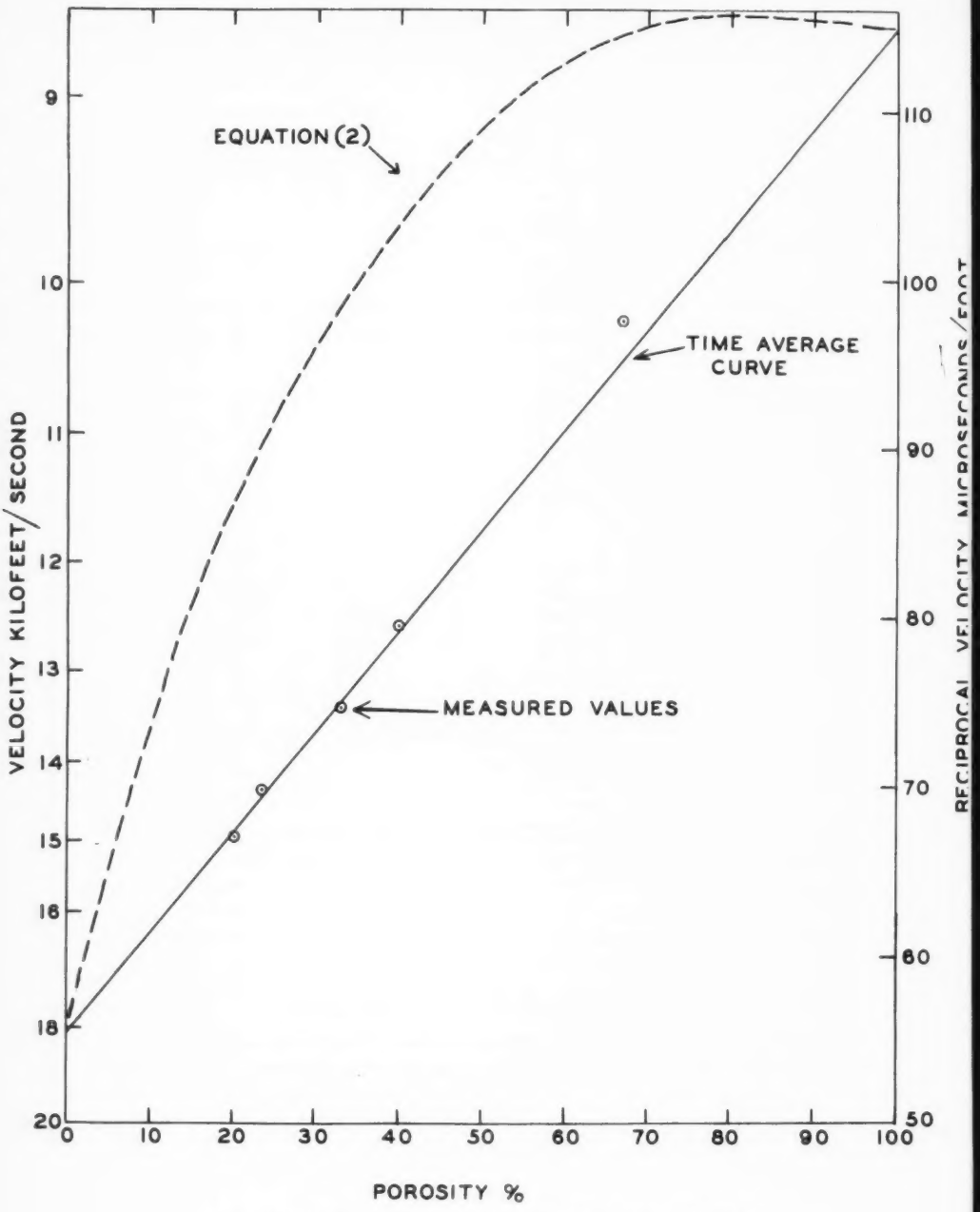

FIG. 6. Velocity versus porosity for glass spheres in methyl methacrylate.

found to be identical with that of Plexiglas moulded from powder; this is not an unexpected result since polymerization of monomer is utilized in the factory production of Plexiglas sheet and powder.

The porosities, i.e., plastic volume/total volume, of the specimens made were altered by varying the proportions of the different sizes of glass spheres used. To achieve a porosity in excess of 40%, the tiny spheres were dispersed in the viscous monomer and polymerization completed before settling occurred.

The time-average curve shown on Figure 6 was calculated from Equation (1) and the second curve by Equation (2). A velocity of 8,600 ft/sec was used for methyl methacrylate and 18,000 ft/sec for glass. It is readily apparent that the

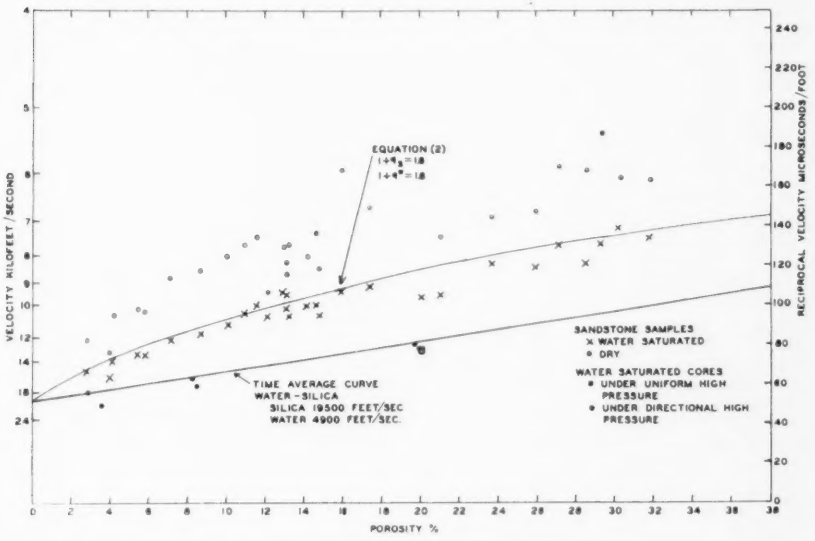

FIG. 7. Velocity versus porosity for sandstone cores.

experimental data fit the time-average curve very well and differ materially from the curve given by Equation (2). This case is that of two solids for which theories for solid-liquid systems might be expected not to apply.

Velocities in Natural Sandstone Specimens

The velocities of a large number of natural sandstone cores were determined under conditions of negligible confining pressure, i.e., subjected merely to the very small vertical compaction caused by the weight of the upper movable crystal holder.

The specimens used were not specially selected and were cut from $4\frac{1}{2}$ inch

diamond cores taken in routine coring operations in Gulf wells in Barbados and Oklahoma. Some Berea, Ohio, sandstone was also examined. All specimens fitted the geological description "sandstone" but the type of material cementing the grains naturally varied; in some specimens it was calcite, in others, silica or clay. In all cases the velocity of a specimen was first measured after oven-drying and cooling and then again after saturating with distilled water. The porosities were obtained gravimetrically by weighing dry and saturated specimens.

Figure 7 shows the results of numerous determinations expressed by reciprocal

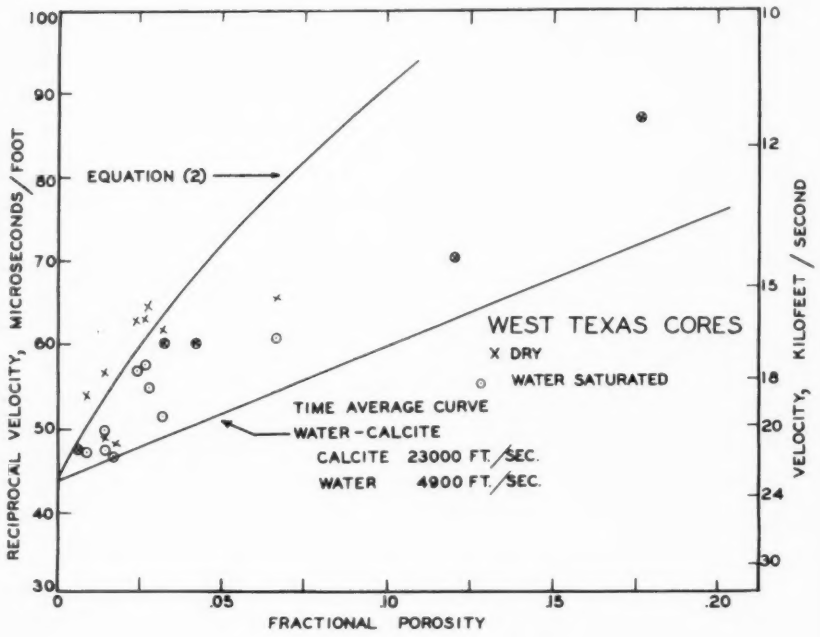

FIG. 8. Velocities of natural limestone cores.

velocity versus porosity. Two curves are shown. Of these, one is marked time-average and has been computed using velocities of 4,800 ft/sec for water and 19,500 ft/sec for silica in Equation (1). The other curve is computed from Equation (2) using a silica velocity of 19,500 ft/sec and with $q_s = 0.6$ and q^* varying from 0.6 to 0.5, the lower value being used at the higher porosities.

For all natural specimens so far tested, the velocity after water saturation is greater than when dry. This behavior was also followed for measured velocities of some carbonate rock specimens from West Texas, for which results are shown on Figure 8. For the calculated time-average velocity and the curve based on

Equation (2), a velocity of 23,000 ft/sec was used for calcite. In Equation (2) both q^* and q_s were set equal to 0.6.

It is evident that for both sandstones, as represented on Figure 7, and limestones, as represented on Figure 8, the time-average velocities are too high. The velocities based on Equation (2) conform reasonably with the experimental determinations made at room temperature and pressure on saturated specimens.

Velocity of Sandstone Specimens as a Function of Water Saturation

In carrying out experiments on partially desaturated sandstone specimens, i.e., containing both water and air, the required saturations were produced by evaporation under controlled conditions. It was found possible by independent experiments to plot a reproducible saturation-time curve for each specimen examined. These calibration curves were obtained for a geometry identical to that which existed when the specimen was put between the crystal heads shown in Figure 1. Thus, when making velocity measurements as a function of saturation, it was unnecessary to remove a specimen from the apparatus during a run. Instead, velocity was measured as a function of time and the appropriate saturation at each time read from the calibration curve.

These velocities were also determined for confining pressures limited to the weight of the upper crystal head. Typical experimental data for three sandstone specimens and two synthetic alundum cores are shown on Figure 9. The measurements on each sample were reproducible and show the following similarities:

For sandstone specimens there is a marked decrease in velocity as saturation is reduced from 100% to about 70%. Between 70% and 10% the velocities are sensibly constant; below 10% they are erratic. For alundum specimens the changes in velocity as the saturation is reduced from 100% to 60% are marked but irregular. At saturations below 60% the velocities are rather constant. Percentagewise, the velocity variations in alundum are much less than in sandstone. Since these results were obtained at atmospheric pressure, they are of uncertain significance when applied to systems under pressure. In the latter regard they differ markedly from pressure experiments on partially saturated specimens reported by Hughes and Kelly (1952, Figure 8).

Velocity of Sandstone Specimens as a Function of Oil and Water Saturation

Two natural sandstone cores with porosities of 21.7% and 21.1% were initially saturated with distilled water (velocity—4,900 ft/sec) and then progressively desaturated using the capillary pressure technique. Oil (Soltrol C, velocity —3,990 ft/sec) was the displacing phase. The velocity of the specimens containing both water and oil were determined at intervals during desaturation. As with the specimens containing air and water, measurements were made with no compacting pressure other than that exerted by the weight of the upper crystal head. The preparation of the samples required removal of the sample from the sample holder between observations but determinations are considered good because they could be repeated at will.

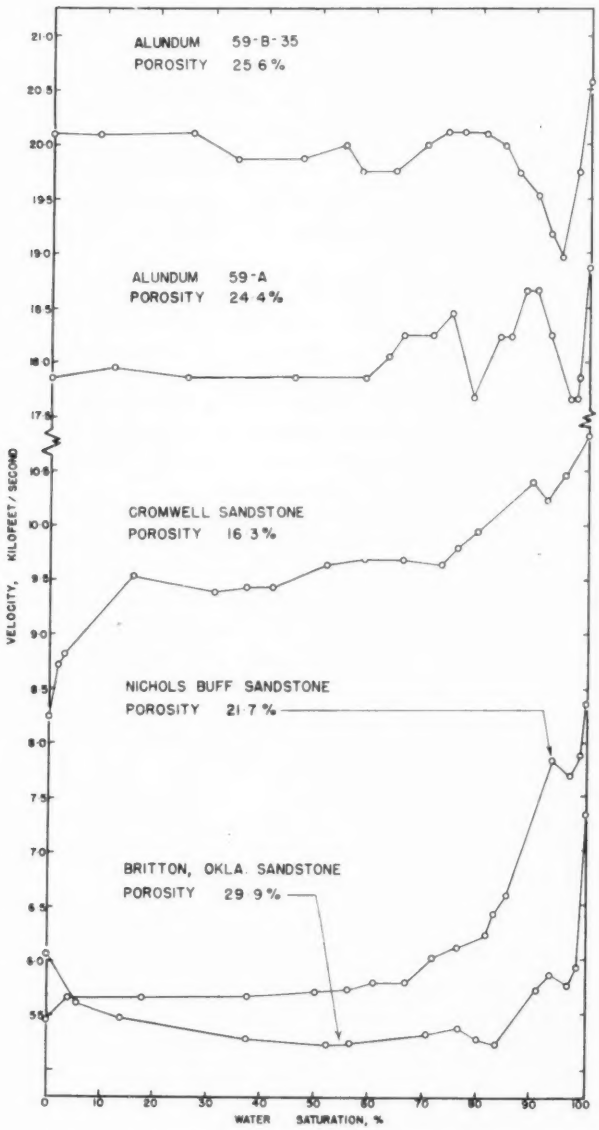

FIG. 9. Velocity as a function of water and air saturation.

Results are shown on Figure 10. It is evident that for both sandstone cores measured, the velocity is highest with 100% water saturation and decreases progressively and materially as water is replaced by oil with a plateau in the range 45 to 65% water saturation. Again, we note that these results should not be applied directly to similar systems subjected to pressure.

Effect of Unidirectional Pressure on Velocity of Sandstone

Right cylinders of rock 1 inch in diameter and 2 inches long were jacketed with rubber sleeves to prevent evaporation losses and axially compressed in a

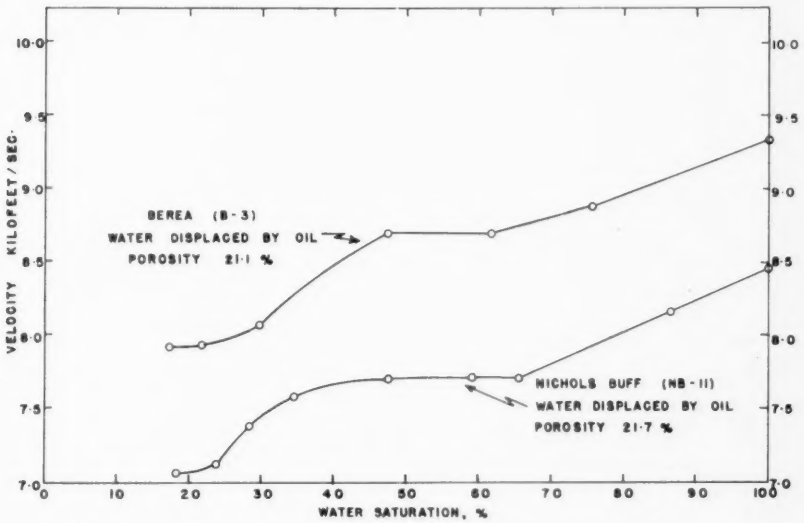

FIG. 10. Velocity as a function of water and oil saturation in sandstone cores.

Loomis hydraulic press (40,000 lb. capacity) between brass heads containing barium titanate crystals. The sample holder, while not identical, is essentially that shown in Figure 1 with the addition of means of loading the crystal heads by measurable amounts.

It was found that velocity increased with applied pressure, as shown in Figure 11, until a limiting velocity was reached. In the case of very high porosity, friable cores, it was apparent that the specimens collapsed before attaining a limiting velocity. In most cases, however, limiting velocities appear to be approached.

Effect of Confining Pressure on the Velocity of Sandstone

We have commenced measurements of material subjected to confining pressures in a hydrostatic pressure chamber. The pressure system is designed for

working pressures up to 15,000 psi. The design is conventional and the equipment consists essentially of a hand pressure pump, a calibrated Bourdon gauge and a pressure container. The container is a standard $6\frac{7}{8}$ inch diameter reaction vessel of the American Instrument Company. Made of chrome-vanadium steel, it has an inside diameter of 5 1/16 inches and an inside height of 20 inches. A specimen holder is mounted inside the chamber. Electrical and fluid connections

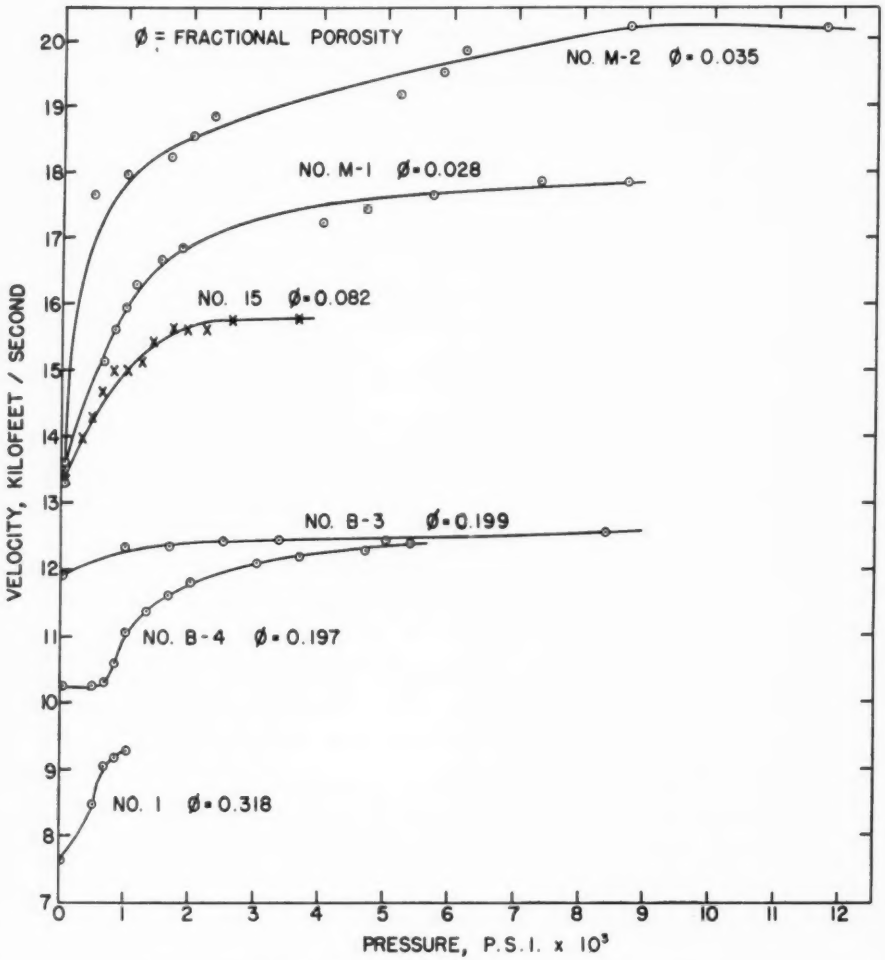

FIG. 11. Directional pressure applied to water saturated sandstone cores.

are made through a detachable cap. A sandstone sample has been copper-jacketed and measured for velocity: (a) dry, (b) 100% water-saturated and (c) 95% water-saturated. Results are shown on Figure 12. The large difference between curves (b) and (c) is particularly noteworthy. The contrast in these curves is attributed to differences in the pressure applied to the water. For curve

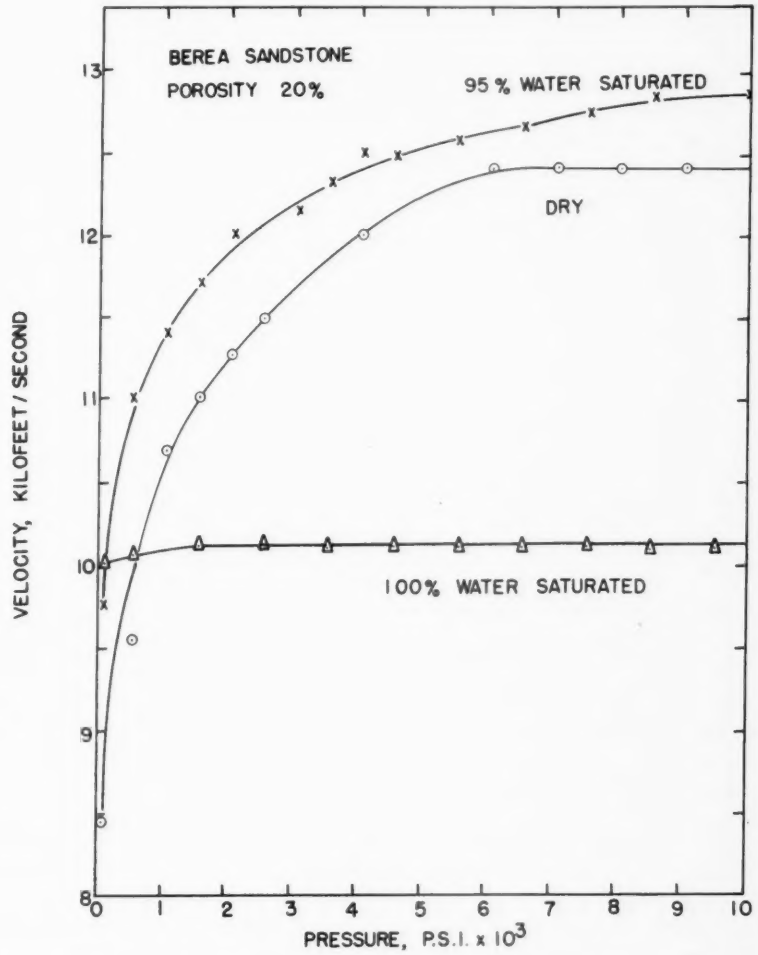

FIG. 12. Effect of uniform pressure on the velocity through a dry, saturated, and partially saturated specimen.

(c) the water (95% saturation) is under comparatively low pressure while the sandstone frame or matrix is under high pressure. Somewhat lower velocities are obtained when the sandstone is dry, curve (a). For 100% water saturation where the water is under relatively high pressure and the matrix under relatively low pressure, much lower velocities are obtained than when the speci-

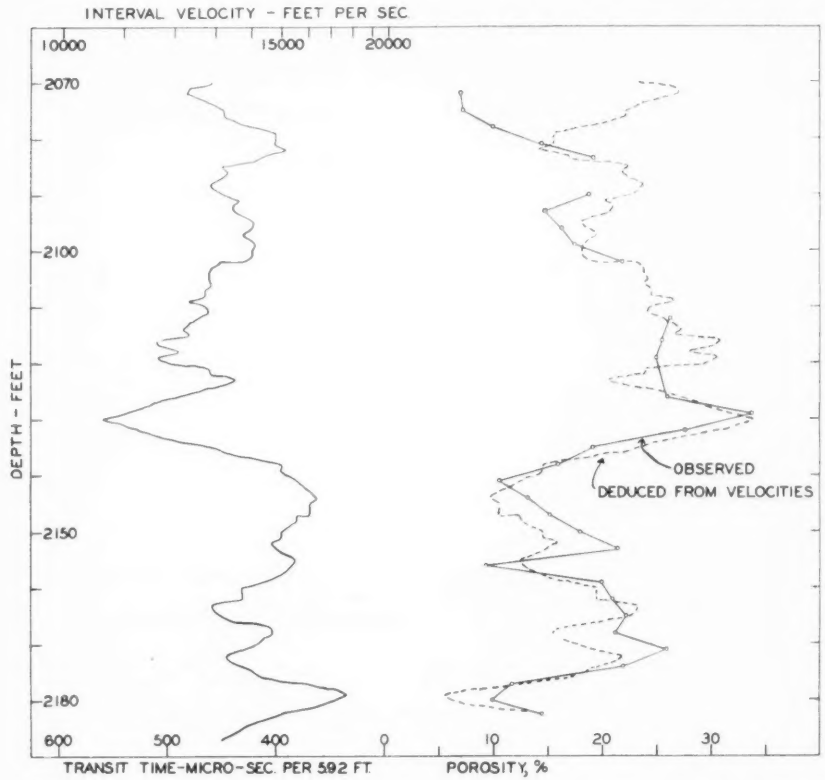

FIG. 13. Comparison I of interval velocity versus porosity data in subsurface limestone—Texas (Data courtesy Magnolia Petroleum Co.)

men is dry or 95% water-saturated. These results are substantially in line with those of Hughes and Kelly (1952). Further investigation of the effect of the pressure of the saturating fluid in a porous medium on velocity is planned.

The limiting velocities from Figures 11 and 12, curve (c), are also plotted on Figure 7 for comparison with velocities of sandstone specimens saturated with water but not subjected to pressure. It will be observed that, except at high porosities where satisfactory limiting velocities could not be measured, the

limiting velocities under pressure give velocities which conform reasonably well with the calculated time-average velocity. When the inevitable heterogeneity of natural sandstones is recollected, the observed conformity is more striking.

Comparison of Interval Velocities in Wells with Porosity

Continuous or interval velocity logging systems such as those described by Summers and Broding (1952), Vogel (1952) and others are now offered as a commercial service. The use of such logs for the correlation of geological strata and

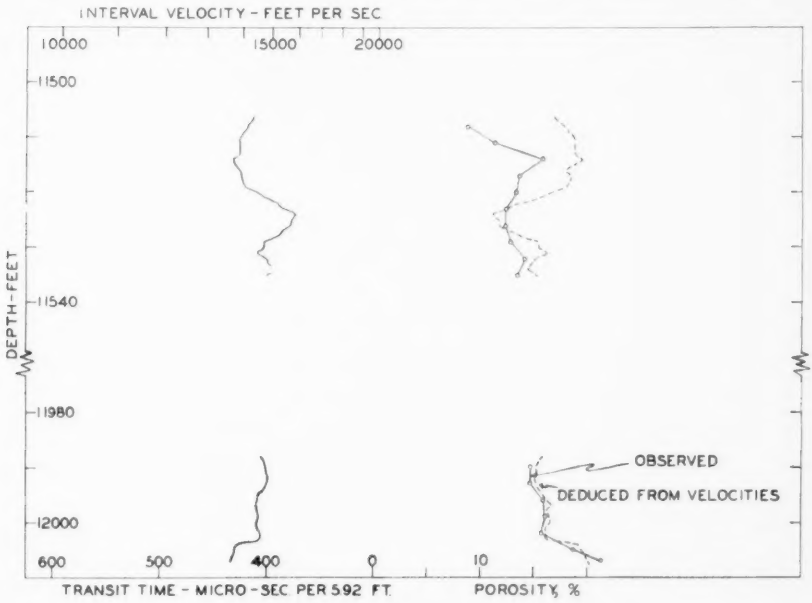

FIG. 14. Comparison II of interval velocity versus porosity data in subsurface sandstone—Miss.

in seismic prospecting is obvious. We are interested in applying them in conjunction with electrical and radioactivity logs in order to evaluate better those properties of porous formations which are of interest to the reservoir engineer.

Some investigations have been made in this direction. The porosities of limestone and sandstone sections present at depth in a number of wells have been determined by analysis of cores. These sections have been selected from wells for which we have interval velocity logs; thus we possess comparative information. Five graphs have been made (Figures 13 to 17) on which measured velocity and porosity are both shown versus depth; one of these involves two different sandstone sections in the same well. It is evident that there is a marked degree

of correlation with velocity generally being relatively low when porosity is relatively high. On each graph another curve is shown representing porosity as deduced empirically from measured interval velocities in a manner to be described.

Figure 18 shows interval velocity versus porosity directly for the data just described. This graph strengthens the correlation with most points tending to fall in a comparatively narrow area greatly elongated along a direction associating decreased velocity with increased porosity. It is quite surprising and striking

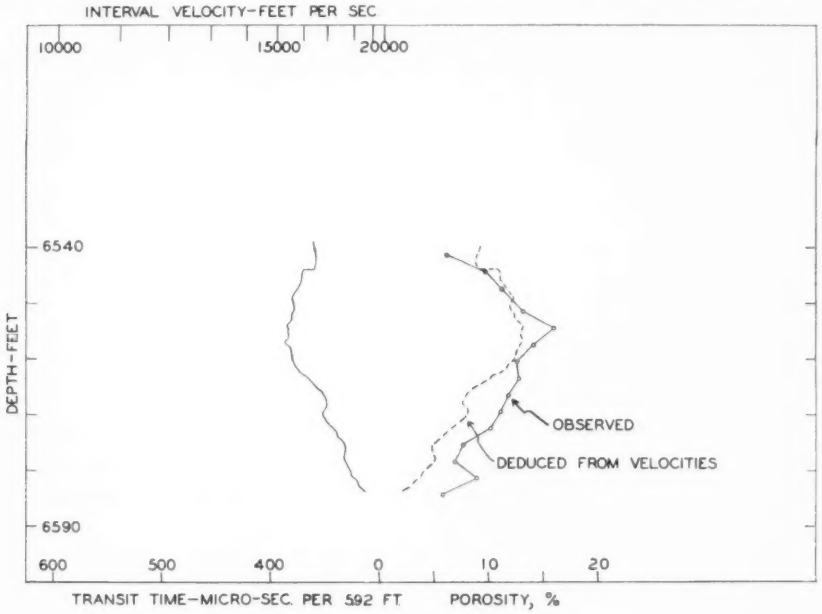

FIG. 15. Comparison III of interval velocity versus porosity data in subsurface sandstone—Okla.

that the data from the several different sections tend to be superposed or to fall in the elongated area with no recognizable discrimination among them. This superposition implies that porosity variations considerably outweigh the influences of (a) differing materials, sandstone or limestone with any impurities; (b) differences in depth which range from 2,000 ft to 11,000+ ft and (c) differences in environment since the sections in question are in different basins and represent an age range from Cretaceous to Ordovician.

A number of additional points are shown on this graph; these represent ultrasonic velocity meter measurements of sandstone samples under pressures of between 400 and 700 atmospheres. Some of these measurements are judiciously

taken from Hughes and Kelly's graphs and some are our own measurements under axial or confining pressure. The self-consistency of these determinations, as well as the agreement with the interval velocity measurements, is noteworthy and further supports the idea that porosity is a dominant factor influencing the velocity of sandstone in particular.

A smooth curve designated Experimental Average has been drawn through

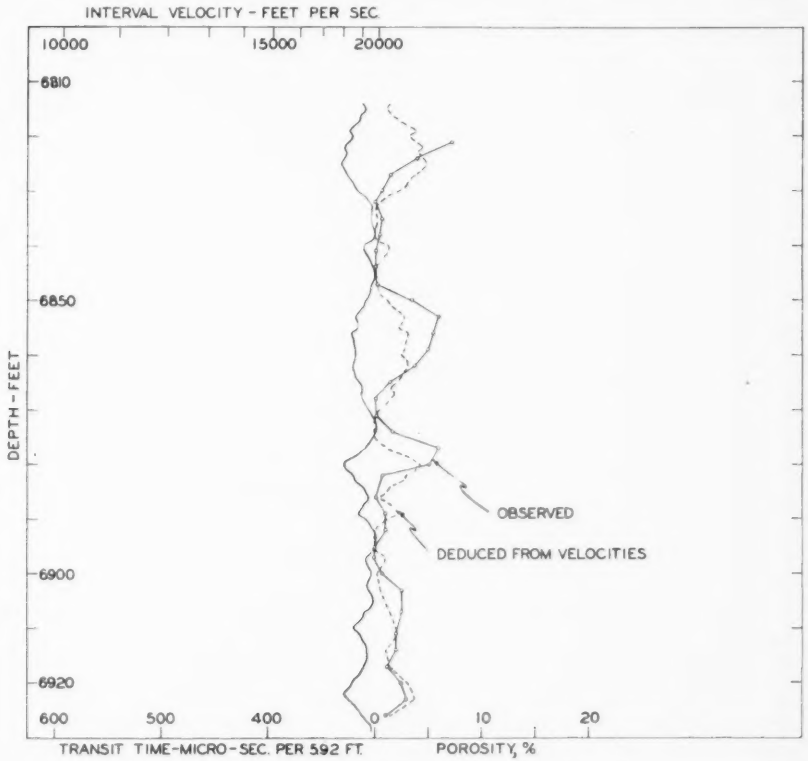

FIG. 16. Comparison IV of interval velocity versus porosity data in subsurface limestone—Texas.

the data on the graph as being representative of a relationship between interval velocity and porosity according to the present limited experimental data. This experimental curve has been used to find porosities empirically that are associated with measured interval velocities. This is the method of obtaining the "empirically deduced" curves shown on Figures 13 to 17.

An interesting observation is that a time-average curve based on a matrix

velocity of 19,500 ft/sec and a liquid velocity of 5,300 ft/sec, also shown on Figure 18, gives a fair fit with many of the experimental data.

DISCUSSION

Whereas all the experimental data show a considerable degree of dependence of velocity upon porosity, there also is a considerable scatter of the data which must represent the influence of other factors. Apart from porosity, velocity may be considered to depend also on the matrix material or materials, grain size distribution and shape, cementation, liquid in pores, pressure and temperature.

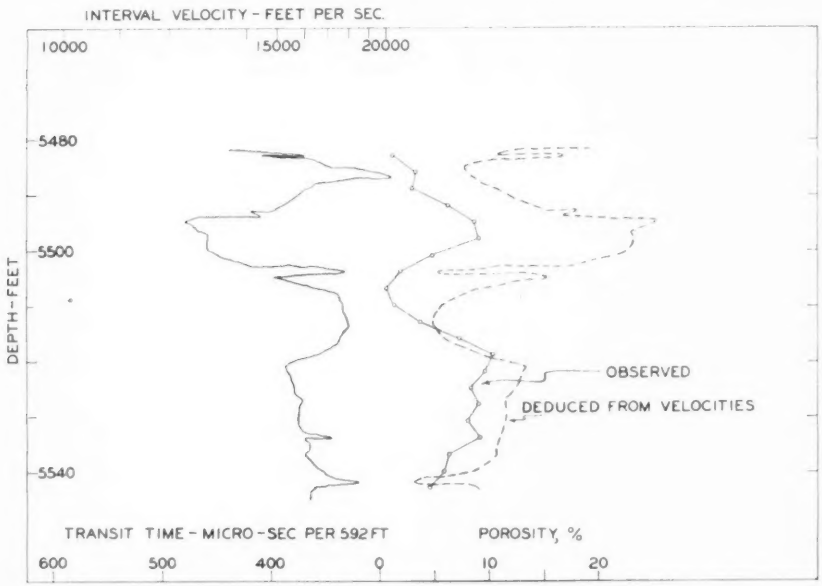

FIG. 17. Comparison V of interval velocity versus porosity data in subsurface limestone—Texas.

Gassmann (1951) has shown that it is necessary to consider (a) the porous rock frame which has elastic properties designated with subscript r, (b) the liquid in the interconnecting pores designated with subscript 1, (c) the solid matter designated with subscript s and (d) the system as a whole designated with no subscript or with an asterisk. Further, the liquid may be under a given pressure while the system is under another pressure or stress. The liquid pressure will act on the solid matter, and the pressure or stress on the porous rock frame is the difference between the pressure or stress on the system and the pressure on the liquid.

If the system is isotropic and consists of grains of any shape resting in a

volume of liquid slightly greater than that just sufficient to fill the pore spaces, or if all of the pressure applied to the system acts on the liquid, there will be simple compression of the solid matter in the rock and the pressure on the rock frame itself will be zero. The compressibility of the system is the average compressibility of the solid and fluid constituents. Expressed in terms of bulk moduli which are the reciprocals of compressibilities, this gives

$$\frac{1}{K^*} = \frac{1-\phi}{K_s} + \frac{\phi}{K_l} \tag{3}$$

The bulk moduli of the different components are related to velocities within

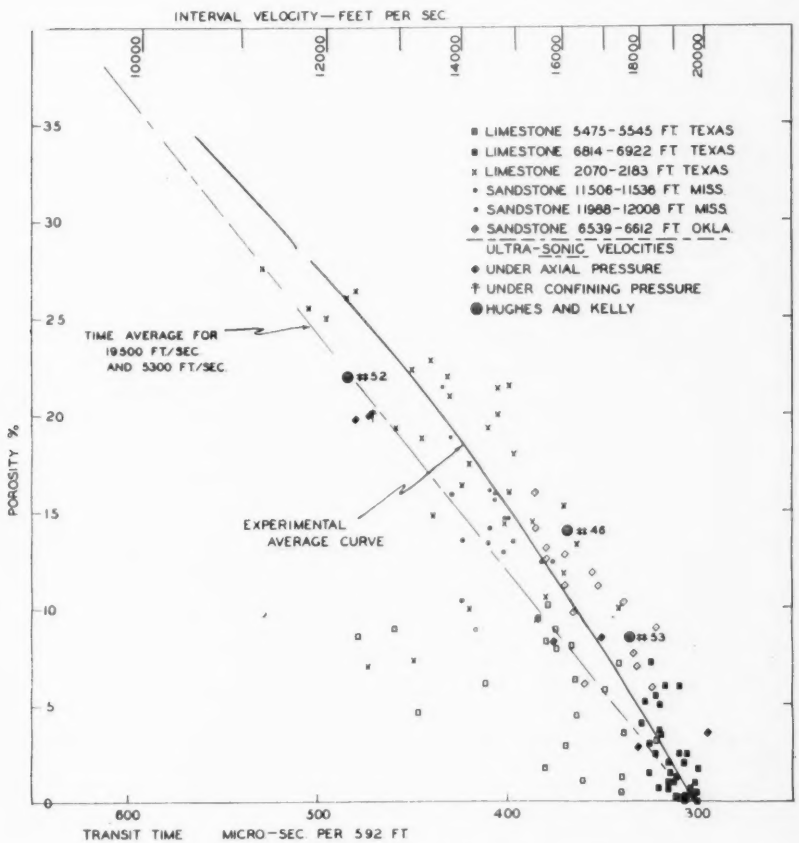

FIG. 18. Direct comparison of interval velocities versus porosity.

these components by the relation

$$K = \frac{\rho V^2}{1 + q}. \tag{4}$$

in which

K = bulk modulus
V = velocity
ρ = density

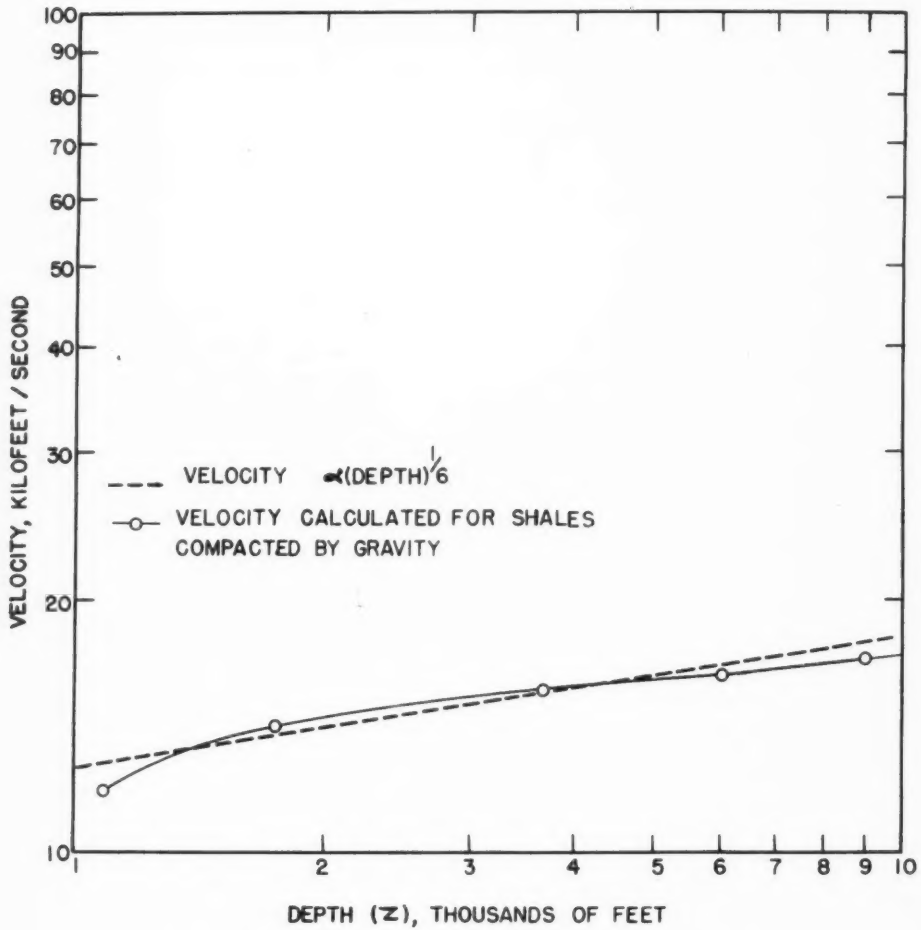

FIG. 19. Comparison between average velocity changes with depth found by Faust and calculated for average shales.

μ = rigidity modulus and ν = Poisson's ratio. $q = 4\mu/3K$ or $2(1-2\nu)/1+\nu)$. From this it follows that $q = 0$ for liquids, 0.61 if Poisson's ratio is 0.3 and 0.8 if Poisson's ratio is 0.25. Equation (2), given above, is obtained by combining Equations (3) and (4).

Calculations using Equation (2) have also been carried through for Samples 46, 52 and 53 of Hughes and Kelly. The determinations of 3,150 m/sec, 2,700 m/sec and 3,650 m/sec compare with respectively experimental values of approximately 4,000 m/sec, 2,500 m/sec and 4,000 m/sec for 100% saturated samples. One of these values agrees quite well with the experimental measurements; the other two determinations are less than the experimental values. The results suggest that, in the experiments, some excess initial fluid in the sample, some leakage and some pressing of the Neoprene jacket into the pore spaces accounted for liquid pressures in the sample equal or approaching the pressure on the system.

Equation (2) becomes Wood's formula (1941) for liquids when the quantities q_s and q^* are zero. The value to use for q^* for a rock system is debatable, but use of 0.6, which is appropriate for a solid, appears to give a fair fit experimentally for liquid-saturated sandstones both at room pressure and when both system and liquid pressures are identical. For loose aggregates, however, q might be expected to approach zero and the results then, except at low porosities, rather closely approach being the same as those given by Wood's formula.

Equation (2) also conforms with the equations obtained by Gassmann (1951) and by White and Sengbush (1953) for saturated rocks under the limiting condition that pressure on the liquid equals the stress on the system (i.e., no stress on the rock frame). Their further analyses considered the effect of stresses on the rock frame in excess of the liquid pressure and thus involved deformation of grain shape. These analyses were made for regular packings of uniform spheres. The deformation considered induces a modifying term which can be calculated to be comparatively small for pressures associated with rock depths of 10,000 ft or less. The applicability of the modifying term to cemented rocks having grain shapes far from spherical is not apparent.

If the pressure on the liquid is substantially less than the pressure on the system, expressed as a ratio θ, the dilatation of the rock frame is equal to the dilatation of the system whence $P/K = P(1-\theta)/K_r$.

For this system then,

$$K = \frac{K_r}{1-\theta}. \tag{5}$$

Here K_r is the bulk modulus of the rock frame and P is applied pressure. Equation (5) connects properties of liquid-saturated rocks subjected to differential pressures on frame and liquid with measurements made on dry rocks subjected to the same net frame pressures.

In considering this equation, it is important to note that K_r is dependent

upon the pressure acting on the frame, $P(1-\theta)$ and decreases with increase in θ so that K is not proportional to $1/(1-\theta)$.

For a "closed system" (i.e., 100% saturated at zero pressure with no ingress or egress of liquid to or from the pore spaces), it can be shown that the limiting fluid pressure/system pressure ratio is equal to K^*/K and Equation (5) becomes

$$K = K_r + K^*$$

a result given by Gassmann.

Some computations based on Equation (5) give results conforming with Hughes and Kelly's measurements and our own in showing slightly higher velocities for incompletely saturated rocks than for dry rocks. The measured velocities are very much higher than those found for completely saturated rocks. Hughes and Kelly's results for saturations between 80 and 95% at zero pressure appear to fall into a critical intermediate position between the two main cases treated. Further experiments are planned to investigate more thoroughly the effect of known liquid pressure upon resultant velocity.

It has been observed by Faust (1953) that, on the average, interval velocities in sand-shale sections increase with depth. He shows also that this increase appears to be proportional to the one-sixth root of the depth. The apparent dependence of velocity on the one-sixth root of the depth has been adduced as evidence in support of Gassmann's relationships between depth and velocity in hexagonal packings of regular spheres. Such a conclusion seems to us unnecessary. Apart from any comments concerning the validity of applying Gassmann's model to cemented porous rocks and shales, a simpler explanation can be based on known relationships between the porosity and depth of burial of shales. It has been shown by Rubey (1927) that, on the average, the porosity of shales is related to their depth of burial by a relationship of the following form:

$$\phi(1-\phi) = C/B \qquad (6)$$

In Equation (6) C is a constant and B the depth of burial; as before ϕ is fractional porosity.

Since, on the average, 80% of any sedimentary section is composed of shale, any velocity changes which accompany porosity changes in shales would be expected to exert a considerable effect on interval velocities measured at various depths. If we take a limiting case, that of intervals composed entirely of shale, it is possible from Equation (6) to find the relative porosity changes which accompany changes in depth of burial. If further we assume that the velocity in shale as a function of porosity is given with reasonable accuracy by a simple time-average calculation, we can compute change in velocity in shale as a function of depth of burial. Figure 19 shows such a calculation (for a shale matrix velocity of 17,500 ft/sec and a liquid velocity of 5,200 ft/sec) and a comparison with the average velocity change found experimentally by Faust. It will be observed that over the depth range 2,000 to 10,000 ft the agreement between the

calculated and observed velocity changes is quite good. For sections containing 20% permeable rock the comparison would not be greatly altered.[1]

In summary, the present investigations with the ultrasonic velocity meter have, in general, been in line with and confirm work of Hughes and others. The investigation has extended measurements to spherical aggregates and a range of sandstone and other samples both liquid-saturated and dry.

Gassmann's general theory has been applied with some success to fit experimental results. We emphasize, however, a somewhat different classification of cases. The "closed system" is indicated not to be easily realized experimentally nor is it to be expected to apply to rocks in the geologic section. For rocks in the geologic section, in general, fluid pressure will be a fractional part of the pressure on the system or "rock pressure" and Equation (5) will apply. This usually leads to a value for saturated rock velocity under pressure which is higher than that of the dry rock.

Measurements of rock velocities in wells obtained from interval velocity logs are related to porosities. A sufficiently close correlation is recognized to afford good prospects that the interval velocity measurements can be used for indicating porosities of sandstones and perhaps limestones after more knowledge has been gained as to the influence of other factors. Such data could greatly assist the interpretation of electric logs. The velocity relation found by Faust for shale and sand-shale sections, i.e. that velocity depends upon the one-sixth power of the depth of burial, is suggested to be due primarily to variations in porosities of shales.

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[1] It can also be shown for permeable sections that the relationship found by Faust between velocity at a particular depth and electrical resistivity is in excellent agreement with a time-average velocity based on the porosity and known average relationships between formation resistivity factor and porosity.

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GEOPHYSICS, VOL. XXI, NO. 1 (JANUARY, 1956), PP. 71-87, 8 FIGS

REFLECTION OF AN ACOUSTICAL PRESSURE PULSE FROM A LIQUID-SOLID PLANE BOUNDARY*

T. W. SPENCER†

ABSTRACT

The problem treated is concerned with predicting the transient response of a system composed of a liquid layer, bounded above by a vacuum and below by a perfectly elastic solid, when excited by an arbitrary pressure applied uniformly over the surface of a spherical cavity located in the fluid. The Laplace transform of the displacement response is expressed in terms of an integral which is expanded in such a way that each term describes the contribution from one of the image sources. Each term may be evaluated exactly at points located on a vertical axis passing through the source. The final expression for the vertical displacement at axial points is composed of the acoustic, afterflow, and correction terms. In solids for which Poisson's ratio is greater than one third the initial variation of the correction is toward positive values (corresponding to motion directed toward the interface). For Poisson's ratio less than one third the initial variation may be either positive or negative depending on the magnitude of the compressional velocity ratio. A surface wave is shown to exist regardless of the choice of parameters. The surface wave velocity is always less than it would be in the absence of the liquid.

INTRODUCTION

The problem considered here is that of predicting the transient response in a liquid layer, which is bounded above by a vacuum and below by a semi-infinite perfectly elastic solid, when a pressure impulse is applied at the surface of a spherical cavity located in the fluid. Pekeris (1948) investigated several important aspects of the problem of elastic wave propagation in a water layer having a fluid bottom in which the velocity exceeds that of water. Press and Ewing (1950) extended Pekeris' treatment to the case of a solid bottom. In both of these studies the analysis consisted of first determining a valid asymptotic solution to the steady state problem at great distances from the source and then in using the Fourier integral to synthesize the transient response resulting from the application of an instantaneous pressure followed by an exponential decay at a point source.

The purpose of this paper is to investigate the transient response in the neighborhood of the interface and to use the results to attain a more precise understanding of the behavior of the interface during and following the reflection. The analysis will serve to illustrate an ingenious approach to problems of this general type which is due to Cagniard (1939). The application of Cagniard's method to this problem yields an exact algebraic expression for the displacement at axial points and permits one to express the displacement at points off the axis in terms of a definite integral from which the existence of a surface wave can be inferred.

* Manuscript received by the Editor May 9, 1955.

† Publications of the Division of the Geological Sciences, California Institute of Technology Pasadena, California—Contribution No. 751.

TRANSIENT RESPONSE AT AXIAL POINTS

This discussion will be limited to a consideration of the response produced in an ideal fluid by an "acoustic" source. The acoustic source acts to produce a pressure differential in the fluid which varies in a prescribed manner over a short time interval. By pressure differential we shall mean the excess or deficiency in the normal hydrostatic pressure produced at a given point by the disturbance. The effects of gravity on the behavior of the fluid at the free surface and upon the density in the undisturbed system are neglected.

In the liquid the displacement and differential pressure may be derived from a potential function ϕ which satisfies the wave equation

$$\frac{\partial^2\phi}{\partial\rho^2}+\frac{1}{\rho}\frac{\partial\phi}{\partial\rho}+\frac{\partial^2\phi}{\partial z^2}=\frac{1}{V_L{}^2}\frac{\partial^2\phi}{\partial t^2} \tag{1}$$

The radial and vertical displacements and the differential pressure are expressed in terms of ϕ by the relations.[1]

$$u_\rho=\frac{\partial\phi}{\partial\rho}, \qquad u_z=\frac{\partial\phi}{\partial z}, \quad \text{and} \quad P=-D_L\frac{\partial^2\phi}{\partial t^2}. \tag{2}$$

The equation which is obtained from (1) by taking the Laplace transform of each term has a solution which may be expressed as an integral over the separation variable λ. The result is

$$\bar{\phi}_P=\int_0^\infty J_0(\lambda\rho)\left[f(\lambda)e^{\alpha z}+g(\lambda)e^{-\alpha z}\right]d\lambda, \tag{3}$$

where $\alpha=(\lambda^2+p^2/V_L{}^2)^{1/2}$. The functions $f(\lambda)$ and $g(\lambda)$ depend upon the nature of the boundary conditions to be imposed. $\bar{\phi}_P$ therefore measures the perturbing influence of the boundaries. In the vicinity of the source the displacement potential must have the form:

$$\begin{aligned}\phi_{S0.} &\equiv 0, && t<r/V_L;\\ &=(a_0/r)f(t-r/V_L), && t\geqq r/V_L.\end{aligned}$$

The Laplace transform of the source function is then

$$\bar{\phi}_{S0.}=\frac{a_0}{r}\int_{r/V_L}^\infty e^{-pt}f\left(t-\frac{r}{V_L}\right)dt. \tag{4}$$

Changing the variable to $\tau(=t-r/V_L)$ leads to the expression

$$\begin{aligned}\bar{\phi}_{S0.}&=\frac{a_0}{r}\int_0^\infty e^{-p(\tau+r/V_L)}f(\tau)d\tau\\ &=\frac{a_0}{r}e^{-pr/V_L}\int_0^\infty e^{-p\tau}f(\tau)d\tau=\frac{a_0\kappa(p)}{rp}e^{-pr/V_L}.\end{aligned}$$

[1] Refer to the list of symbols (p. 87) for an explanation of the terms used.

$\kappa(p)$ depends only upon the function selected to represent the pressure variation at the source cavity. It is clear that the pressure is assumed to be uniform over the cavity surface at every instant of time. It is now possible to express any source function in terms of cylindrical coordinates by means of the identity

$$\frac{a_0\kappa(p)}{rp}e^{-pr/V_L} = a_0\kappa(p)\int_0^\infty \frac{\lambda}{p\alpha}J_0(\lambda\rho)e^{-\alpha|z-h|}d\lambda. \tag{5}$$

The transform of the total response must therefore have the form

$$\bar{\phi}(p;\rho,z) = \int_0^\infty \left[a_0\kappa(p)\frac{\lambda}{p\alpha}e^{-\alpha|z-h|} + f(\lambda)e^{\alpha z} + g(\lambda)e^{-\alpha z}\right]J_0(\lambda\rho)d\lambda. \tag{6}$$

The solution in the solid is obtained from the equations for the propagation of the scalar and vector potentials ψ and U. The vector potential is introduced to describe the effects resulting from the initiation of transverse waves at the liquid-solid boundary. The equations for the potentials are

$$\nabla^2\psi = \frac{1}{V_S^2}\frac{\partial^2\psi}{\partial t^2} \tag{7}$$

and

$$\nabla^2 U - \frac{U}{\rho^2} = \frac{1}{v_S^2}\frac{\partial^2 U}{\partial t^2}. \tag{8}$$

The radial and vertical displacements and the normal and tangential stresses are related to the potentials by the equations:

$$u_\rho = \frac{\partial\psi}{\partial\rho} - \frac{\partial U}{\partial z}, \qquad u_z = \frac{\partial\psi}{\partial z} + \frac{\partial U}{\partial\rho} + \frac{U}{\rho}, \tag{9}$$

$$\tau_{zz} = \lambda_S\nabla^2\psi + 2\mu_S\left\{\frac{\alpha^2\psi}{\partial z^2} + \frac{1}{\rho}\frac{\partial^2(\rho U)}{\partial z\partial\rho}\right\},$$

and (10)

$$\tau_{\rho z} = \mu_S\left\{2\frac{\partial^2\psi}{\partial\rho\partial z} - 2\frac{\partial^2 U}{\partial z^2} + \frac{1}{v_S^2}\frac{d^2U}{\partial t^2}\right\}.$$

The equations obtained from (7) and (8) after taking the Laplace transform have the solutions

$$\bar{\psi}(p;\rho,z) = \int_0^\infty h(\lambda)J_0(\lambda\rho)e^{-\beta z}d\lambda, \tag{11}$$

and

$$\bar{U}(p;\rho,z) = \int_0^\infty j(\lambda)\frac{dJ_0(\lambda\rho)}{d\rho}e^{-\gamma z}d\lambda. \tag{12}$$

α, β, and γ all have the same form. β differs from α only in the substitution of V_S for V_L; similarly γ is obtained from α by substituting v_S for V_L.

The coordinate system is chosen in such a way that the XY plane lies in the surface of the liquid and z is considered positive when it lies below this surface. The arbitrary functions $f(\lambda)$, $g(\lambda)$, $h(\lambda)$, and $j(\lambda)$ are determined by requiring that: (a) the normal component of stress vanish at the surface, (b) the tangential component of stress vanish at the interface, (c) the normal component of displacement be continuous at the interface, and (d) the normal component of stress be continuous at the interface. These conditions are satisfied if:

(a) $a_0\kappa(p)(\lambda/p\alpha)e^{-\alpha h} + f(\lambda) + g(\lambda) = 0$;

(b) $\beta e^{-\beta d}h(\lambda) + \Omega e^{-\gamma d}j(\lambda) = 0$;

(c) $-a_0\kappa(p)(\lambda/\alpha)e^{-\alpha(d-h)} + \alpha f(\lambda)e^{\alpha d} - \alpha g(\lambda)e^{-\alpha d}$
$= -\beta h(\lambda)e^{-\beta d} - \lambda^2 j(\lambda)e^{-\gamma d}$;

(d) $D_L p^2\{a_0\kappa(p)(\lambda/p\alpha)e^{-\alpha(d-h)} \quad f(\lambda)e^{\alpha d} + g(\lambda)e^{-\alpha d}\}$
$= 2D_S v_S^2\{\Omega h(\lambda)e^{-\beta d} + \gamma\lambda^2 j(\lambda)e^{-\gamma d}\}$;

where $\Omega = (\lambda^2 + p^2/2v_S^2)$. These conditions yield the following expressions for the functions of λ:

$$f(\lambda)D(\lambda) = a_0\kappa(p)\,\frac{\lambda}{p\alpha}\,e^{-\alpha d}(G - H)(e^{\alpha h} - e^{-\alpha h}), \tag{13a}$$

$$g(\lambda)D(\lambda) = -a_0\kappa(p)\,\frac{\lambda}{p\alpha}\{(G - H)e^{-\alpha(d-h)} + (G + H)e^{\alpha(d-h)}\}, \tag{13b}$$

$$h(\lambda)D(\lambda) = a_0\kappa(p)\,\frac{D_L}{D_S}\,\frac{\lambda p\Omega}{\alpha v_S^2}\,e^{\beta d}(e^{\alpha h} - e^{-\alpha h}), \tag{13c}$$

$$j(\lambda)D(\lambda) = -a_0\kappa(p)\,\frac{D_L}{D_S}\,\frac{p\lambda\beta}{\alpha v_S^2}\,e^{\gamma d}(e^{\alpha h} - e^{-\alpha h}), \tag{13d}$$

where

$$G(\lambda) = \Omega^2 - \gamma\beta\lambda^2, \tag{14a}$$

$$H(\lambda) = (D_L/D_S)(\beta/\alpha)(p^4/4v_S^4), \tag{14b}$$

and

$$D(\lambda) = (G + H)e^{\alpha d} + (G - H)e^{-\alpha d}. \tag{14c}$$

For the present we will confine our attention to the liquid. We obtain the final expression for the transform of the displacement potential in the form

$$\bar{\phi}(p; \rho, z) = a_0\kappa(p)\left[\int_0^\infty \left\{e^{-\alpha|z-h|} + e^{\alpha z}\left[\frac{A(\lambda)e^{-2\alpha d}(e^{\alpha h} - e^{-\alpha h})}{1 + A(\lambda)e^{-2\alpha d}}\right]\right.\right.$$
$$\left.\left. - e^{-\alpha z}\left[\frac{e^{-\alpha h} + A(\lambda)e^{-\alpha(2d-h)}}{1 + A(\lambda)e^{-2\alpha d}}\right]\right\}\frac{\lambda}{p\alpha}\,J_0(\lambda\rho)d\lambda\right], \tag{15}$$

where $A(\lambda)=(G-H)/(G+H)$. The denominator $1+A(\lambda)\exp(-2\alpha d)$ may be expanded and the series integrated term by term provided it can be shown that the series is uniformly convergent for all values of $\lambda(0\leqq\lambda<\infty)$. This series will be uniformly convergent if the value of the function $A(\lambda)\exp(-2\alpha d)$ can be shown always to lie in the interval between plus and minus one. Make the substitution $\lambda=pu$. The value of G at $u=0$ is $(S_3^4/4)p^4$. It is easy to show that G is always positive and is always $\geqq(S_3^4/4)p^4$. The fact that the compressional velocity is always greater than the transverse velocity implies that

$$p^4u^2\left[u^2+S_3^2\right]^{1/2}\left\{\left[u^2+S_3^2\right]^{1/2}-\left[u^2+S_2^2\right]^{1/2}\right\}\geqq 0;$$

therefore if the multiplication is carried out and the expression $(S_3^4/4)p^4$ is added to each side of the inequality the desired result is obtained. Since G and H

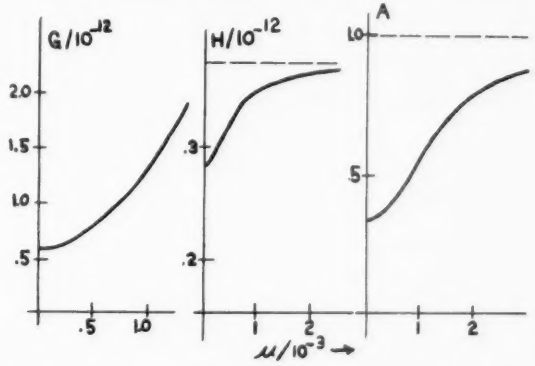


FIG. 1. The functions G, H, and A have been plotted for the case where the density ratio is $2/3$; $V_L=1{,}500$ meters per second; $V_S=2{,}000$ meters per second; and the Poisson's ratio is .4. The dotted lines indicate the values which the functions H and A approach asymptotically. G diverges in the same manner as the function $(u^2/2)(S_3^2-S_2^2)$.

are always positive and greater than zero, A must have a value between plus and minus one. It should be noted, however, that A can be made to approach as close to unity as we desire simply by allowing either the density ratio to approach zero or the rigidity to approach infinity. In the discussion which follows it will be found that if $A\equiv 1$ the solid acts as a perfect reflector. It is not difficult to convince one's self that the inequality holds in all cases of physical interest.

H is independent of u for the special case in which the compressional velocities are equal. Also if $D_LV_L/D_SV_S\geqq 1$, A must pass through zero as u varies between zero and infinity. Graphs of G and H are plotted in Figure 1 for a special case.

The response function (15) can now be expressed in the form

$$\bar{\phi}(p;\rho,z)$$

$$=a_0\kappa(p)\left[\int_0^\infty\frac{\lambda}{p\alpha}e^{-\alpha|z-h|}J_0(\lambda\rho)d\lambda-\int_0^\infty\frac{\lambda}{p\alpha}e^{-\alpha(z+h)}J_0(\lambda\rho)d\lambda\right.$$

$$+\int_0^\infty \frac{\lambda}{p\alpha} J_0(\lambda\rho)A(\lambda)\{e^{-\alpha(2d-h-z)} - e^{-\alpha(2d+h-z)} - e^{-\alpha(2d-h+z)} + e^{-\alpha(2d+h+z)}\}d\lambda$$

$$+\int_0^\infty \frac{\lambda}{p\alpha} J_0(\lambda\rho)A^2(\lambda)\{-e^{-\alpha(4d-h-z)} + e^{-\alpha(4d+h-z)} + e^{-\alpha(4d-h+z)} - e^{-\alpha(4d+h+z)}\}d\lambda$$

$$+ \cdots]. \tag{16}$$

The first term is the response due to the source. The second term describes the wave which has been perfectly reflected at the surface with a phase reversal. Succeeding terms have been arranged according to the number of times the wave

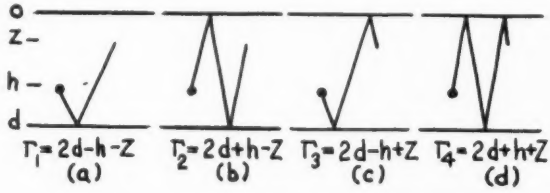


FIG. 2. Ray paths for the waves which have been reflected once from the interface.

has been reflected from the interface. The terms in the third integral describe the waves which have been reflected once from the interface (see Figure 2).

The "reflection integrals" can be evaluated on the axis ($\rho = 0$) by straightforward procedures. Consider for example the integral

$$\bar{\phi}_{\Gamma_i} = \pm a_0 \int_0^\infty \frac{u}{a} J_0(pu\rho)A^n(u)e^{-pa\Gamma_i}du. \tag{17}$$

The value of n indicates the number of times the wave has been reflected from the liquid-solid interface. The sign of $d\Gamma_i/dz$ indicates from which boundary the wave was last reflected. If the derivative is minus one the last reflection was from the interface; if the derivative is plus one the last reflection was from the surface. The sign in front of the integral is positive if the wave has been reflected an even number of times from the surface and negative otherwise. The expression for Γ_i specifies the location of the ith image source.

In the discussion which follows our primary objective will be to gain a better understanding of the interaction between liquid and solid during the reflection process. In order to do this we consider that the free surface is sufficiently far removed from the point of observation to make it unnecessary to consider the effects produced by the multiply reflected waves. The total response at such a point is then just the sum of the effects produced by the direct wave and the wave reflected from the interface. If in the expression for $\bar{\phi}_{\Gamma_i}$ we let $n = 1$, $\Gamma_i = \Gamma_1$, and choose the plus sign, then the displacement potential found by mathematical manipulation of the integral will describe the wave which has been reflected

once from the interface. The components of the displacement in the reflected wave are found by taking the derivative of $\bar{\phi}_{\Gamma_1}$ with respect to z and ρ. In this manner we obtain the relations

$$\bar{u}_z(p;\rho,z) = a_0 p \int_0^\infty u J_0(pu\rho) A(u) e^{-pa\Gamma_1} du \tag{18}$$

and

$$\bar{u}_\rho(p;\rho,z) = -a_0 p \int_0^\infty \frac{u^2}{a} J_1(pu\rho) A(u) e^{-pa\Gamma_1} du. \tag{19}$$

For $\rho = 0$, the first order Bessel function is identically zero and the transform of the radial displacement vanishes. The vanishing of the transform requires that the radial displacement itself must be identically zero for all time at axial points.

The evaluation of the vertical displacement at axial points is a fairly simple matter. For $\rho = 0$, $J_0(pu\rho) = 1$, and (18) reduces to

$$\bar{u}_z(p;0,z) = a_0 p \int_0^\infty u A(u) e^{-pa\Gamma_1} du.$$

Make the substitution $t = a\Gamma_1$, $du/dt = a/u\Gamma_1$; then

$$\begin{aligned} \bar{u}_z(p;0,z) &= -\frac{a_0}{\Gamma_1} \int_{S_1\Gamma_1}^\infty aA \frac{d(e^{-pt})}{dt} dt \\ &= \frac{a_0}{\Gamma_1} \left\{ [(aA)_{t=S_1\Gamma_1}] e^{-pS_1\Gamma_1} + \int_{S_1\Gamma_1}^\infty e^{-pt} \frac{d(aA)}{dt} dt \right\}. \end{aligned} \tag{20}$$

In the integral we make the substitution $A = 1 - B$ ($B = 2H/G+H$). This is done so that the terms which describe the afterflow and the motion produced in the liquid by the propagation of elastic waves along the interface can be considered separately. We obtain

$$\begin{aligned} \bar{u}_z(p;0,z) = a_0 \Bigg\{ & \frac{S_1}{\Gamma_1} \frac{1-\chi}{1+\chi} e^{-pS_1\Gamma_1} + \frac{1}{\Gamma_1} \int_{S_1\Gamma_1}^\infty e^{-pt} \frac{d(a)}{dt} dt \\ & - \frac{1}{\Gamma_1} \int_{S_1\Gamma_1}^\infty e^{-pt} \frac{d(aB)}{dt} dt \Bigg\}, \end{aligned} \tag{21}$$

where $\chi = D_L V_L / D_S V_S$. The reason for making the substitution is now apparent. The first integral is simply the Laplace transform of the unit step function $1(t - S_1\Gamma_1)/\Gamma_1$. The second integral is the transform of the function $\xi(t;0,z)$, defined as follows:

$$\left.\begin{aligned} \xi(t;0,z) &\equiv 0, \qquad t < S_1\Gamma_1; \\ &= -(a_0/\Gamma_1) d(aB)/dt = -(a_0/\Gamma_1^2)(a/u) d(aB)/du, \quad t \geqq S_1\Gamma_1 \end{aligned}\right\}. \tag{22}$$

The first term is interpreted as the Laplace transform of the Dirac delta function $\delta(t-S_1\Gamma_1)$.[2] The final expression for the vertical displacement in the reflected wave may now be put in the form

$$\begin{aligned} u_z(t;0,z) &\equiv 0, \qquad t < S_1\Gamma_1; \\ &= a_0\left[\left\{(1-\chi)/(1+\chi)\right\}(S_1/\Gamma_1)\delta(t-S_1\Gamma_1) + 1(t-S_1\Gamma_1)/\Gamma_1^2 \cdot \right. \\ &\quad \left. - (1/\Gamma_1^2)(a/u)d(aB)/du\right], \qquad t \geqq S_1\Gamma_1 \end{aligned} \tag{23}$$

The first and second terms add nothing new to our understanding of the reflection process. The third term is the correction term. On the axis the amplitude of this term decreases inversely as the square of the distance from the image source. It therefore represents a correction to the afterflow. It is important to note that the effect of making the density ratio arbitrarily small is to cause the correction term to vanish while leaving the afterflow term unaffected.

A spreading of the correction term accompanies its propagation. The characteristics (i.e.—maximum and minimum) of the function ξ depend only on the value of u while the time depends on the values of both u and Γ_1. This means that the time difference between two points of the correction curve, u_1 and u_2, increases linearly with the distance from the image source according to the relation

$$t_2 - t_1 = \Gamma_1\left\{(u_2^2 + S_1^2)^{1/2} - (u_1^2 + S_1^2)^{1/2}\right\}. \tag{24}$$

If $u_2-u_1=\Delta u$; and $\Delta u \ll u_1, u_2$; then $t_2-t_1=\Gamma_1 u_1\Delta u/(u_1^2+S_1^2)^{1/2}$. In this approximation it is clear that the amount of spreading increases toward the tail of the wave.

CALCULATIONS AND INTERPRETATION

Detailed calculations of the time dependence of the function $-\Gamma_1^2\xi/a_0$ were made for three choices of the elastic parameters.

Case	Poisson's Ratio	Compressional Velocity (mt./sec.)		Density Ratio D_L/D_S
		Solid	Liquid	
I	0.4	2,000	1,500	2/3
II	0.4	2,000	500	2/3
III	0.2	6,000	1,500	1/2

The choice of parameters in Case I should be appropriate for describing the wave which has been reflected from a moderately well compacted solid having small resistance to shearing stresses. In Case III the solid has properties similar to those of granite.

The curves of Figure 3 have been drawn for the special case in which the

[2] The significance attached to the delta function will be discussed later. For a rigorous mathematical treatment of functions of this type see the paper by Mikusinski (1950).

source is located two meters above the interface and the reflected wave is observed at a point midway between the source and the interface. Each of these curves has a discontinuous beginning and each approaches zero asymptotically from negative values. The function $(-\Gamma_1^2/a_0)\xi$ has the asymptotic form

$$-(D_L/D_S)S_3^4/u^2(S_3^2 - S_2^2). \tag{25}$$

The effect of changing the liquid velocity is at once apparent when cases I and II are compared. Case II is marked by a much larger discontinuity and a more rapid oscillation between its maximum and minimum values. Case III is different from the other two in three important ways: (1) the amplitude is negative originally; (2) there is no oscillation in the amplitude; and (3) instead of decaying

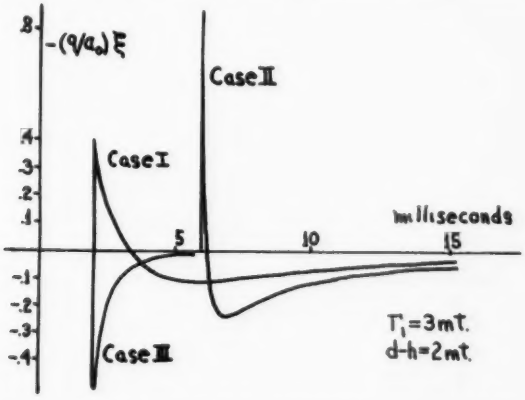


FIG. 3. The time variation of that part of the vertical displacement which depends on the correction term. The response is shown for three choices of the elastic parameters. The source is located two meters above the interface and the point of observation is one meter above the interface.

immediately after the discontinuous beginning, the amplitude increases slightly to a maximum negative value.

To shed some light upon the reason for these differences Figure 4 was constructed. In this figure $-(\Gamma_1^2/2a_0)\xi(S_1\Gamma_1; 0, z)$ has been plotted as a function of the ratio of the compressional velocities $\eta(=V_L/V_S)$ for different values of Poisson's ratio and for a fixed value of the density ratio. The expression from which these curves were obtained can be put in the form

$$-(\Gamma_1^2/2a_0)\xi(S_1\Gamma_1; 0, z) = (D_L/D_S)\eta/(1 + (D_L/D_S)\eta)$$
$$\left[\left\{1/(1 + (D_L/D_S)\eta)\right\}\left\{(1/\eta^2)\left[1 - 8(S_2^2/S_3^2)(1 - S_2/S_3)\right] - 1\right\} + 1\right]. \tag{26}$$

The dependence of the sign of this function upon the elastic parameters can be investigated by determining the values of Poisson's ratio for which there exists a value of η which causes the expression in the outer square brackets to vanish.

Equating this expression to zero leads to an equation from which the desired information can be extracted; namely,

$$(D_L/D_S)\,\eta_0^3 = 8(S_2^2/S_3^2)(1 - S_2/S_3) - 1. \tag{27}$$

η_0 has a real positive value only if the term on the right is greater than or equal to zero. This means that the velocity ratio v_S/V_S must satisfy the equation

$$(v_S/V_S)^2(1 - v_S/V_S) \geqq 1/8. \tag{28}$$

The positive roots of this equation are 0.500 and 0.809. In actual materials Poisson's ratio cannot be less than zero and the velocity ratio cannot exceed $2^{-1/2}$. This means that it is always possible to find a value of η which makes

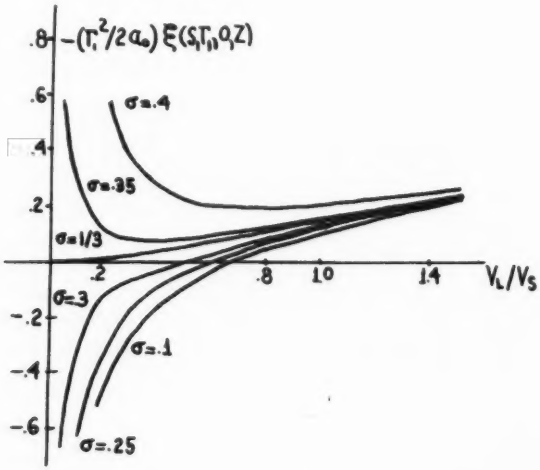


FIG. 4. The initial value of the correction term plotted as a function of the compressional velocity ratio for different values of Poisson's ratio and for a density ratio of 2/3.

equation (26) vanish if Poisson's ratio lies between zero and one-third. It should be noted that η_0 has a maximum value for a Poisson's ratio of one-tenth. If curves corresponding to Poisson's ratios less than one-tenth had been included in Figure 4 it would have been found that they cross the horizontal axis slightly to the left of the point where the curve corresponding to a Poisson's ratio of one-tenth crosses the horizontal axis. How far to the left may be readily determined from equation (27). For a Poisson's ratio of zero and for a density ratio of two-thirds (which was used in calculating the curves in Figure 4) this distance is about 0.009 units.

The interpretation of Figure 4 and the correction curves cannot be carried out in a satisfactory manner unless certain points of the discussion, which were

passed over rather rapidly, are clarified at this point. First it is important to distinguish between the correction term and the expression which describes the actual motion of the interface at the axial point. The correction term describes the effect upon the fluid of the propagation of elastic waves along the surface of the solid. The actual motion of the interface at the axial point can be expressed in the form

$$u_z(t; o, d) = -\{a_0/(d-h)\}[(1/V_L)(2\chi/(1+\chi))\delta(t-(d-h)/V_L) + \{1/(d-h)\}(a/u)d(aB)/du]. \tag{29}$$

The presence of the delta function indicates that the incident wave produces an instantaneous displacement oscillation in the negative direction (upward).[3] The absence of an afterflow term indicates that the displacement at the axial point approaches zero asymptotically according to equation (25).

A second point which requires clarification is the role played by the Dirac delta function. This function enters at the stage of evaluation represented by equation (23). Now actually each term in equation (21) must be thought of as being multiplied by the function $\kappa(\dot{p})$ which depends on the particular time variation in pressure chosen to represent the source. For a physically realizable source the function $\kappa(\dot{p})$ cannot have the constant value unity (see footnote below). This means that the inverse of the function $\kappa(\dot{p})\exp(-pS_1\Gamma_1)$ should have been found and not the inverse of the function $\exp(-pS_1\Gamma_1)$. It is clear that if this had been done the result obtained would have been identical with the result which is obtained when equation (23) is inserted into the superposition integral. We therefore do not attach any significance to the Dirac delta function when it appears by itself but only to the term obtained from it after integration. If we bear this in mind then it is possible to reach some interesting conclusions without actually carrying through the numerical integrations. These conclusions are not restricted to a specific variation in the source pressure, as they would be if the inversion had been carried out directly, but apply equally well to a broad class of physically realizable source conditions.

The response of the system to an arbitrary pressure variation, which has associated with it a displacement potential ϕ_g, can be found from the superposition theorem. This theorem states that the total response R_g is related to the response produced by an input step function in the displacement potential by means of the relation

[3] If $\kappa(\dot{p})=1$ then the input pressure would have a time variation represented by minus the derivative of the Dirac delta function and the input potential by the unit step function. To show this calculate the displacement potential in an infinite fluid which is subjected to a pressure variation at the source represented by one cycle of a sine wave (consider the case where the initial variation of the pressure is toward negative values). In the expression for the displacement potential allow the pressure amplitude P_0 to go to infinity and the period T_0 to approach zero in such a way that the quantity $P_0T_0^2/2\pi D_L$ approaches unity.

$$R_\varphi(t;0,z) = \phi_\varphi(0)u_z(t) + \int_0^{t-S_1\Gamma_1} \frac{d\phi_\varphi}{d\tau}\, u_z(t-\tau)d\tau. \tag{30}$$

Actually we shall only be interested in that part of the response which depends on the correction term; accordingly we replace $u_z(t-\tau)$ by $\xi(t-\tau)$ in (30). It may be readily verified that in the resulting expression both the response and its time derivative vanish at $t=S_1\Gamma_1$ if the function ϕ_φ and its time derivative vanish at $\tau=0$ and if the derivative of ϕ_φ is continuous. Furthermore if these conditions are satisfied then the initial variation of the time derivative of the displacement potential must be toward negative values when the initial variation of the source pressure is toward positive values. This fact indicates that if the initial variation in the source pressure is toward positive values then the initial variation in the sign of the function $-\xi$ will be preserved in the process of superposition. Figure 4 therefore provides information about the relationship between the sign of the correction term at its beginning and the elastic properties of the system. It is this relationship which will be of primary interest in interpreting the response curves in terms of the behavior of the interface. Further progress cannot be made without actually specifying the form of the pressure variation. When the response curves have been suitably fitted, the superposition theorem can be used to predict characteristic features of the response initiated by a specific pressure variation (e.g.—the frequency dependence of the response could be determined by using for the source pressure one cycle of a sine wave). It is interesting to note that for a single sinusoidal oscillation in pressure of sufficiently high frequency the effect of superposition is to make the initial value of the correction term and its time derivative zero and to multiply each point of the response curve (at times $>S_1\Gamma_1+T_0$) by the factor $-P_0T_0^2/2\pi D_L$, where P_0 is the amplitude of the sine wave and T_0 is the period.

These preliminaries were required before attempting to interpret Figure 4 and the response curves. Descent along a vertical line in Figure 4 corresponds to changing the elastic properties of the solid in such a way that the compressional velocity is unaffected while the transverse velocity is continuously increased. The relationships between the elastic constants which will be of interest in the present discussion are

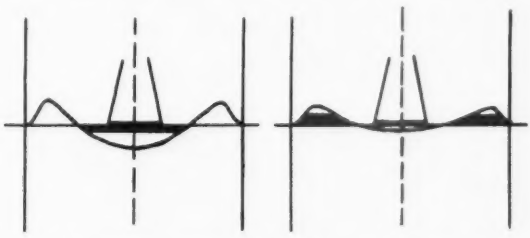
$$v_S^2 = (V_S^2/2)(1-2\sigma)/(1-\sigma), \qquad \mu_S = (D_SV_S^2/2)(1-2\sigma)/(1-\sigma),$$
$$k_S = (D_SV_S2/3)(1+\sigma)/(1-\sigma), \text{ and } E_S = D_SV_S^2(1+\sigma)(1-2\sigma)/(1-\sigma). \tag{31}$$

Changing Poisson's ratio from .5 to 0 increases the transverse velocity, the rigidity, and Young's modulus and decreases the incompressibility. This means that if the behavior of two elastic solids, which have the same densities and compressional velocities, is studied during a short time interval following the arrival of the disturbance it will be found that the solid which has the larger value of Poisson's ratio will undergo a larger distortion of the interface, a deeper indentation at the point of application, and a smaller over-all change in volume.

It is possible clearly to visualize the response of the solid in terms of the rate

at which the wave front spreads out over the surface and the lateral extent of the interacting area. Consider that the wave arrives at the time $(d-h)S_1$. After an infinitesimal time interval the radius of the interacting area will be given by the expression $r_1 = V_L\left[\{((d-h)/V_L)+\epsilon\}^2 - \{(d-h)/V_L\}^2\right]^{1/2}$. For example if the input pressure had a time variation represented by one cycle of a sine wave and if ϵ were set equal to one half of the period then r_1 would be the radius of the region over which the pressure is larger than its equilibrium value.

Sketches have been made in Figures 5A and 5B which illustrate in a schematic way the effect of vertical pressure on two solids which have the same compressional velocity and different values of Poisson's ratio. The part of the interface lying within the cone indicates the radial extent of the interacting area at a time $(d-h)S_1+\epsilon$. The solid vertical lines indicate the distance reached by the compressional wave in the time interval ϵ. The dark area denotes the net volume



FIGS. 5A and 5B. Schematic representation of the behavior of two solids a short time after the arrival of the direct wave. The Poisson's ratio in Figure 5A is larger than in Figure 5B, the compressional velocities are the same in both figures. The dark area indicates the net volume change of the solid: negative in Figure 5A and positive in Figure 5B.

change produced as a result of the interaction. If the Poisson's ratios in Figures 5A and 5B are 0.4 and 0.1 then the ratios of the elastic parameters are

$$k_{.1}/k_{.4} = 11/21, \qquad \mu_{.1}/\mu_{.4} = 8/3, \quad \text{and} \quad E_{.1}/E_{.4} = 44/21.$$

The situation in Figure 5A corresponds to the case where the initial effect of the interaction is to produce a decrease in the volume of the solid. In Figure 5B the initial effect of the interaction is to produce a positive change in volume. These sketches describe in a qualitative manner the initial behavior of two solids when the velocity in the liquid is a small fraction of the compressional velocity in the solid. It seems legitimate to interpret the correction curves in Figure 3 as recovery curves. In cases I and II the initial effect of the disturbance is to produce a decrease in volume. This decrease in volume causes the predominant initial flow in the neighborhood of the axial point to be directed toward the interface. In case III the initial effect is to produce an increase in volume and a flow away from the interface. The response curves therefore describe the flow which accompanies the deformation of the interface and the effect of the recovery of the solid on the liquid as the disturbance is propagated outward from the axial point.

Examination of Figure 4 shows that for sufficiently large values of V_L the initial motion is always directed towards the interface. We interpret this fact in the following manner. Consider that the pressure in the incident wave is positive throughout the time interval ϵ and that $\epsilon \ll S_1(d-h)$. This means that the radius of the circle, drawn with the axial point as its center, which is being subjected to a positive vertical pressure increases with the square root of the liquid velocity. The pressure near the periphery of the interacting region must be equalized mainly by shearing stresses set up in the solid as a result of the interaction. Within the interacting region the incident pressure must be equalized to a large extent by compressive forces. This seems to indicate that it is the lateral extent of the area over which the pressure can be applied in a time interval ϵ, rather than the elastic properties of the solid, which determines the initial behavior of the correction term for large values of V_L.

For very small values of η the curves are observed to diverge. At first glance this fact does not seem to be in accord with the physical nature of the problem. However, it has been found that if η is allowed to approach zero then the discontinuity not only increases in value but also the rate of decay. The effect of using the superposition integral is to reduce this very large oscillation in displacement to a quite small value. This is due to the fact that the time interval for which the large values of ξ contribute to the integral becomes infinitesimal (24). For small values of V_L it is clear that nearly the whole reaction occurs at the instant the disturbance first reaches the interface—effectively the influence of the disturbance upon the solid is not felt after this time. If V_S is large then v_S must be large also and the initial effect of the disturbance must be propagated outward from the axial point with a very high velocity.

SURFACE WAVES

This close-knit dependence between the correction term and the elastic parameters becomes even more apparent when we consider the question of surface waves. The existence of a surface wave is usually associated with the presence of a pole in the integrand of the integral for the displacement potential (17). This means that if for any choice of parameters the function $G+H$ can be shown to vanish for some value of u in the complex plane then the existence of a surface wave can be inferred. In the discussion which follows we show that in all cases the function $G+H$ has two zeros which are located on the imaginary axis and are complex conjugates of each other and then prove that they are the only zeros.

In Figure 6 the general behavior of the functions G and H has been indicated when u is restricted to motion along the negative imaginary axis. In all cases the zero occurs for a value of u which exceeds u_R (the Rayleigh pole). This fact indicates that the presence of a liquid decreases the velocity of propagation of the surface wave. In case III the velocity of the surface wave and V_L approach each other as the liquid velocity approaches zero. This fact seems to indicate that in this case it is the liquid velocity which is most important in determining the velocity of the surface wave.

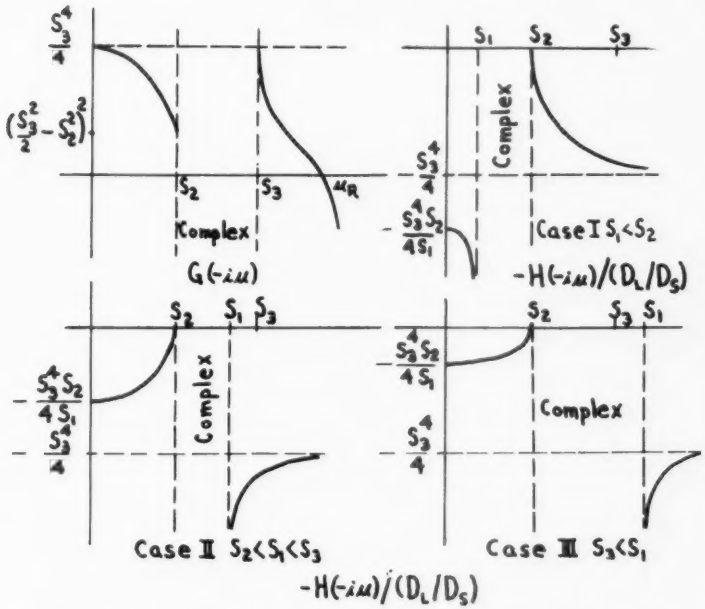
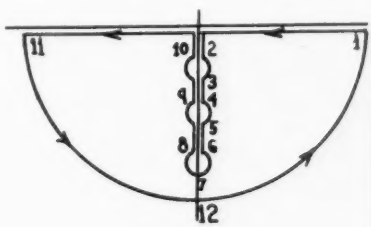


FIG. 6. The real part of the functions G and H have been plotted for u values on the negative imaginary axis. The values of S_2 and S_3 are fixed and arbitrary. Three graphs of H have been plotted corresponding to the possible relationships between S_1, S_2, and S_3.

To prove that there is only one zero of the function $G+H$ in the lower half of the complex plane it is necessary to show that the mapping of the contour of Figure 7 in the $G+H$ plane makes only one complete circuit about the origin. The mapping of the contour of Figure 7 in the G and H planes is indicated in Figure 8 for the case where $S_1<S_2<S_3$. The contour in the H plane lies com-



Point	Value of u
1	$\infty - i\epsilon$
2	$\epsilon - iS_1 + i\eta$
3	$\epsilon - iS_1 - i\eta$
4	$\epsilon - iS_2 + i\eta$
5	$\epsilon - iS_2 - i\eta$
6	$\epsilon - iS_3 + i\eta$
7	$-iS_3 - i\eta$
8	$-\epsilon - iS_3 + i\eta$
9	$-\epsilon - iS_2 + i\eta$
10	$-\epsilon - iS_1 + i\eta$
11	$-\infty - i\epsilon$
12	$-i\infty$

FIG. 7. Contour in the u plane used to investigate the zeros of the function $G+H$.

pletely to the right of the imaginary axis. The infinite semi-circle is the contribution to H from a circle of infinitesimal radius in the u plane having $-iS_1$ as its center. This behavior of the function H is found regardless of the choice of the elastic parameters.

The mapping of the contour of Figure 7 in the G plane makes one complete circuit about the origin provided S_1 does not exceed S_3. This to is be expected since the Rayleigh pole lies within the contour. If S_1 exceeds S_3 the contour in the G plane may or may not enclose the origin depending on whether or not S_1 exceeds the Rayleigh pole. If S_1 exceeds the Rayleigh pole the mapping will not enclose the origin. Points between $-iS_3$ and $-iS_1$ will be mapped onto the real axis and points between $-iu_R$ and $-iS_1$ have negative real values. In all cases the semi-infinite circle in the u plane maps onto the G plane as the infinite circle.

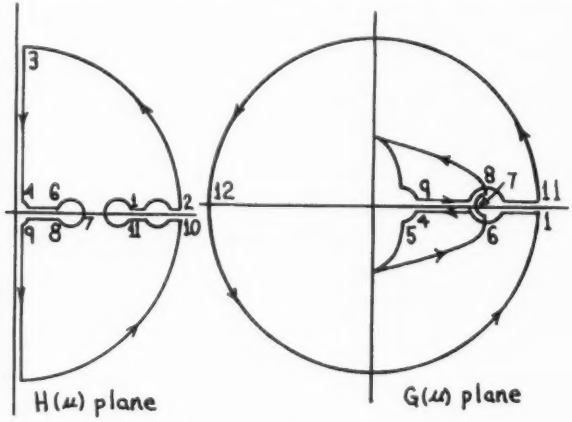


FIG. 8. Mappings of the contour of Figure 7 on the G and H planes.

To obtain the mapping in the $G+H$ plane it is necessary to make a vector addition of the values of G and H corresponding to each value of u on the contour of Figure 7. In the final mapping if S_1 does not exceed u_R then all points will lie to the right of the imaginary axis except those points which are the mapping of points in the u plane which lie on the semi-infinite circle. If S_1 exceeds u_R some of the points which lie between $-iu_R$ and $-iS_1$ will also have negative real parts but these points must have large imaginary parts. In both cases the semi-infinite circle is mapped onto the $G+H$ plane as an infinite circle about the origin. It appears then that in all cases the final mapping must have one and only one zero within the contour of Figure 7. The same argument may be used to demonstrate the existence of one and only one zero in the upper half of the u plane.

ACKNOWLEDGMENTS

The author is deeply indebted to Professor C. H. Dix for bringing to his attention Cagniard's work and for many very informative discussions concerning it.

SYMBOLS

$\bar{(\ )}$	Laplace transform of the corresponding quantity
$(\ )_S$	subscript S refers to solid
$(\ )_L$	subscript L refers to liquid
ϕ	displacement potential—liquid
ρ	radial distance from axis
z	vertical distance from surface
t	time
V	compressional sound velocity
u_ρ	radial displacement
u_z	vertical displacement
P	differential pressure
D	density
λ	separation variable
p	parameter which appears in Laplace transform
r	distance from source center
a_0	source radius
h	depth of source
d	depth of liquid
ψ	displacement potential—solid
U	vector potential—solid
v_S	transverse sound velocity
μ_S, λ_S	Lame's constants
τ_{zz}	vertical stress component
$\tau_{z\rho}$	tangential stress component

$S_1 = 1/V_L$, $S_2 = 1/V_S$, $S_3 = 1/v_S$

$a = (u^2 + S_1^2)^{1/2}$, $b = (u^2 + S_2^2)^{1/2}$, $c = (u^2 + S_3^2)^{1/2}$

η	ratio of compressional velocities (liquid/solid)
σ	Poisson's ratio
k_S	incompressibility
E_S	Young's modulus
u_R	Rayleigh pole

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GEOPHYSICS, VOL. XXI, NO. 1 (JANUARY, 1956), PP. 88-106, 3 FIGS.

REGIONAL GRAVITY SURVEY IN NORTHEASTERN OKLAHOMA AND SOUTHEASTERN KANSAS*

KENNETH L. COOK†

ABSTRACT

In 1948 the U. S. Geological Survey, in cooperation with the U. S. Coast and Geodetic Survey, made a regional gravity survey in northeastern Oklahoma and southeastern Kansas in connection with the studies of the deflection of the vertical. About 550 gravity stations were occupied with spacings of 5 to 10 miles in parts of 54 counties, and a Bouguer anomaly map, contoured at intervals of 5 milligals, was drawn.

In southeastern Kansas there is a lack of correlation of regional gravity with known regional structural geology. The observed gravity anomalies are apparently caused principally by variations of density in the Precambrian basement and indicate a basement of complex nature, made up of rocks of contrasting properties, with a regional grain striking predominantly west or west-northwest.

In northeastern Oklahoma the several observed regional gravity anomalies indicate different degrees of correlation of regional gravity with regional structural geology. In the Precambrian highland area in Osage, Pawnee, and Creek Counties, there is a lack of correlation, as the gravity anomaly is probably caused chiefly by density contrasts within the basement complex. The anomaly associated with the Hunton arch is probably caused partly by structural relief of the rocks of pre-Pennsylvanian age and partly by density contrasts within the basement, and thus indicates some correlation. The steep gravity gradients along the outer flanks of the Ozark uplift indicate good correlation with the subsurface geology. The great anomaly over the Arkansas basin, which indicates a close correlation, is probably caused largely—but perhaps not entirely—by downwarping of the basement and pre-Pennsylvanian rocks.

INTRODUCTION

During April to June 1948 the U. S. Geological Survey, in cooperation with the U. S. Coast and Geodetic Survey, made a regional gravity survey in northeastern Oklahoma and southeastern Kansas (Fig. 1). The survey was made to supplement the information that private geophysical and oil companies had made available to the Coast and Geodetic Survey in its studies for the Army Map Service of the deflection of the vertical; no gravity data were made available for northeastern Oklahoma and southeastern Kansas.[1] This paper gives the results of the regional gravity survey of that area and discusses briefly some of the problems incident to the interpretation of the gravity features observed.

FIELD OBSERVATIONS AND TECHNIQUES

A Frost gravimeter with double thermostatic control and a sensitivity of 0.07215 milligal per dial division was used throughout the survey. The drift of this instrument was usually not more than 0.3 milligal during any single day.

In Oklahoma, readings were taken at about 370 gravity stations, located at points forming approximately rectangular patterns with 5 to 10-mile spacings

* Presented at the St. Louis meeting of the Society, April 25, 1951. Manuscript received by the Editor July 22, 1954. Publication authorized by the Directors, U. S. Geological Survey and U. S. Coast and Geodetic Survey.

† U. S. Geological Survey and University of Utah, Salt Lake City, Utah.

[1] Personal communication from Capt. A. J. Hoskinson, U. S. Coast and Geodetic Survey.

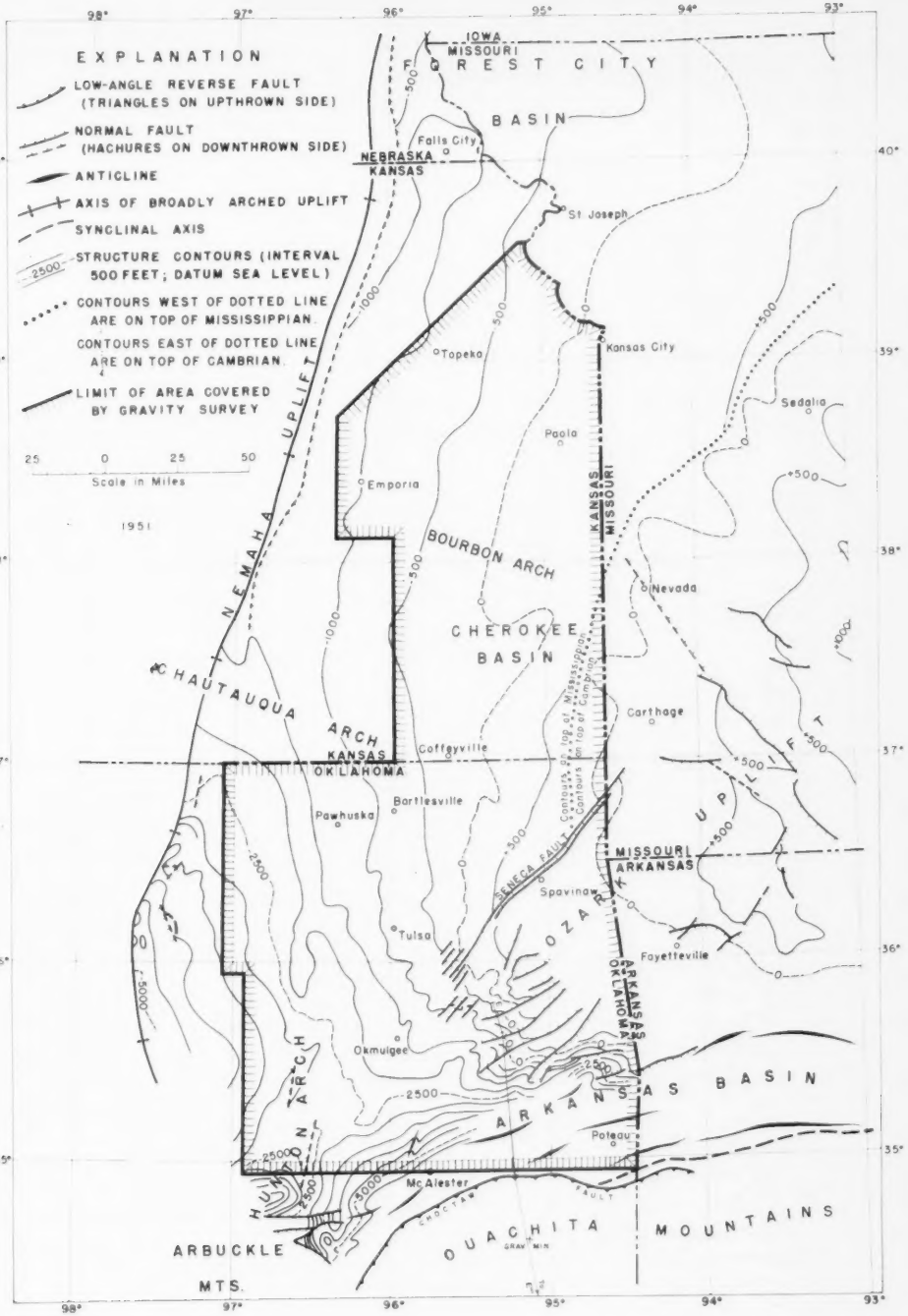


FIG. 1. Sketch map showing area covered by gravity survey and simplified regional tectonic features within and adjacent to surveyed area. (Taken mainly from "Tectonic Map of the United States," published by the American Association of Petroleum Geologists, 1944.)

between individual stations, in parts of 30 counties (Fig. 2). In Kansas, readings were taken at about 180 stations, located similarly but with about 10-mile spacings between individual stations, in parts of 24 counties. A base net with a total of 22 gravimeter base stations was established, and 16 U. S. Coast and Geodetic Survey pendulum stations were occupied.

To provide a relatively accurate base of reference for the gravity values, each gravimeter base station was tied to one or more nearby base stations of the net by alternating two or more pairs of gravimeter readings. Some of the U. S. Coast and Geodetic Survey pendulum stations were similarly tied accurately to the gravimeter base stations.

The elevations of all the stations were taken by the U. S. Coast and Geodetic Survey, using the single-base altimeter method.

REDUCTION OF DATA

Except for ties between gravimeter base stations or between base stations and pendulum stations, the instrument readings were not usually corrected for drift.[2] The average value of all the readings of a base station taken on any one day was used as the reference value of the base station for the day. Using this method of calculation, repeat readings taken at the same field station on different days could generally be made within an accuracy of about 0.1 milligal; the difference exceeded 0.2 milligal in rare cases only.

The datum for the reductions was mean sea level, and the theoretical gravity at sea level was determined from the International Gravity Formula (U. S. Coast and Geodetic Survey, 1942). The U. S. Coast and Geodetic Survey computed the free-air anomalies, and I added the Bouguer correction. At the suggestion of Joseph A. Sharpe, the value of 2.57 was used in the Bouguer correction as a reasonably good average density of the near-surface sedimentary rocks included in the surveyed area.

Terrain corrections were not made for any of the gravimeter stations. The terrain corrections for the 16 U. S. Coast and Geodetic Survey pendulum stations taken in 1948 at widespread points within the surveyed area (Duerksen, 1949), as determined by taking the difference between the simple Bouguer correction and the complete Bouguer correction to zone 0, do not exceed 0.6 milligal. As the corrections are less than 0.5 milligal for most of the pendulum stations, the same is probably true for most of the gravimeter stations.

Isostatic reductions were not applied to the data.

REGIONAL GRAVITY AND REGIONAL GEOLOGY

Bouguer anomalies

The map shown in Figure 2 gives the simple Bouguer anomalies in the surveyed area. The contour interval is 5 milligals. A part of the Bouguer gravity

[2] The readings taken at a few regular gravimeter stations in the extreme southeast corner of Kansas, where the proximity of the ambient temperature to the operating temperature of the instrument caused considerable drift temporarily, were corrected for drift.

anomaly map of Missouri, published by the Missouri Geological Survey and Water Resources (1943) with a contour interval of 50 gravity units (equivalent to 5 milligals), is included on the map to show the continuation of trends. As the density used to make the Bouguer correction for the Missouri map[3] was different from the density that I used for the Oklahoma-Kansas map, and as the reference pendulum stations for observed absolute gravity for the Missouri survey were different from those for the Kansas-Oklahoma survey, the contours are offset at the Missouri-Oklahoma and Missouri-Kansas state lines.

Southeastern Kansas

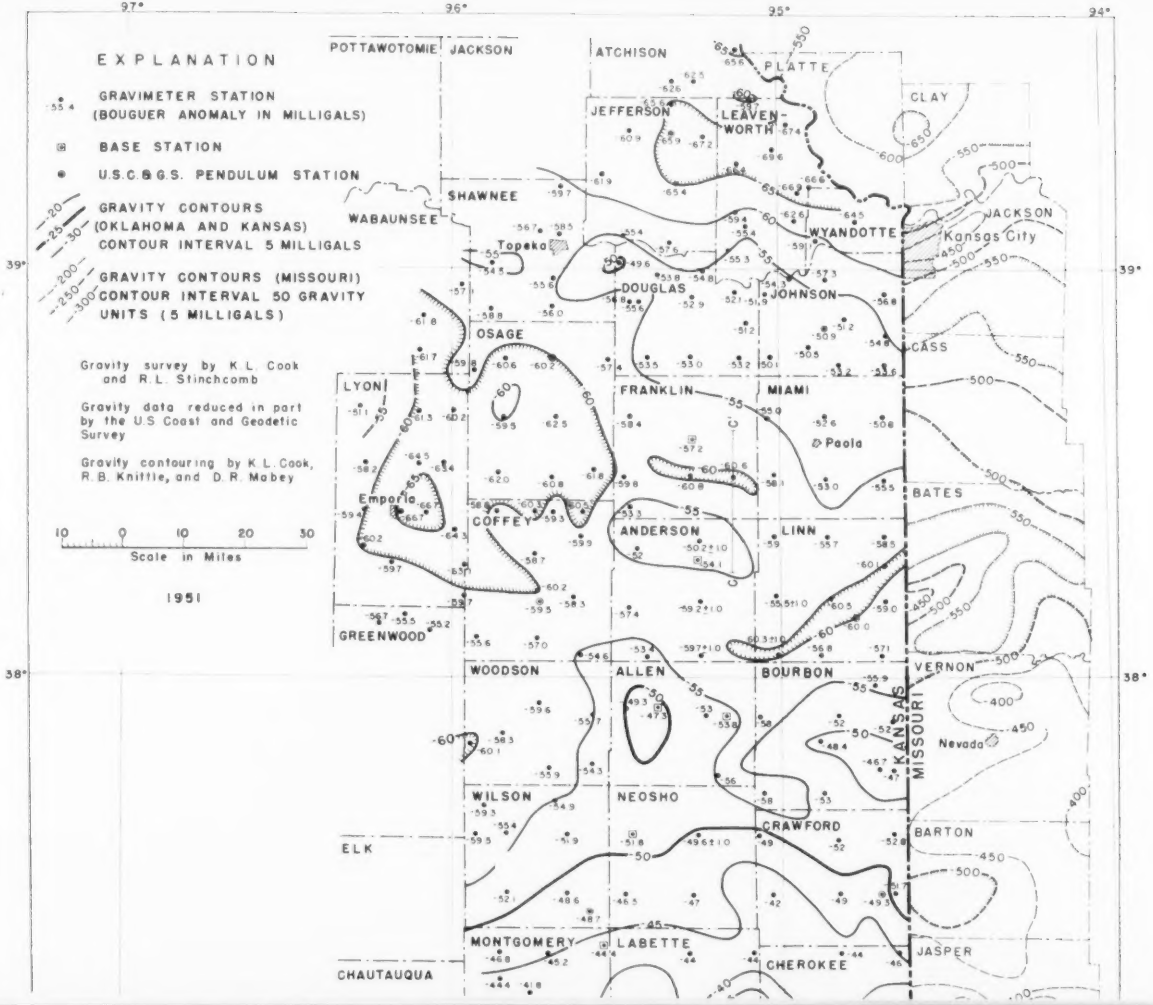
The principal structural features within the surveyed area in Kansas (Fig. 1) are the Chautauqua arch, developed before Mississippian time, and the Forest City basin, Cherokee basin, and the weak Bourbon arch, all developed mainly after Mississippian time (Lee, 1943 and 1946). The sedimentary rocks within the surveyed area in Kansas dip mainly west (see the contours on top of the Mississippian system in Figure 1; also Lee, 1946, cross section, sheet 7). The complete sedimentary section is about 1,500 feet thick in eastern Crawford County and about 2,800 feet thick in northwestern Woodson County (Fig. 3). As shown by the contours on top of the Precambrian rocks in Figure 3, the present surface of the basement complex dips west and northwest in Kansas. Future detailed work will probably reveal more irregularities than indicated by the smooth and sweeping contours that were based on sparse data averaging only about one well per county.[4]

Except for some minor similarities that will be discussed presently, none of the observed gravity anomalies agrees closely with any one of the principal structural features in Kansas.

In the southern part of Kansas in the surveyed area, the wavy, eastward-trending gravity contours indicate a persistent gravity decrease northward totaling about 20 milligals. This eastward-trending gravity belt adjoins an eastward-trending zone of irregular gravity contours that apparently extends eastward into Jasper and Lawrence Counties, Missouri. The location and trend of this gravity belt corresponds approximately with the location and trend of the axis of the Chautauqua arch. Except possibly in the southern part of Mont-

[3] According to a personal communication from E. L. Clark, State Geologist of Missouri, the density value 2.67 was used for the Bouguer correction on that part of the Missouri map included in Figure 2.

[4] Since the map of the basement surface in Kansas was compiled in 1935, several recent wells to the Precambrian, some of which are included in Figure 3, have indicated that slight modifications of the contours are needed; but I have not attempted to make such modifications as they apparently would not greatly alter the general regional picture of the basement configuration. Data for all the Precambrian wells in Kansas were not available to me. The trough indicated in the basement in Franklin County is based on untrustworthy data obtained from only one hole (shown in Fig. 3) in the southern part of Miami County, which was drilled before 1930 (personal communication from Wallace Lee).


EXPLANATION
GRAVIMETER STATION (BOUGUER ANOMALY IN MILLIGALS)
BASE STATION
U.S.C.&G.S. PENDULUM STATION
GRAVITY CONTOURS (OKLAHOMA AND KANSAS) CONTOUR INTERVAL 5 MILLIGALS
GRAVITY CONTOURS (MISSOURI) CONTOUR INTERVAL 50 GRAVITY UNITS (5 MILLIGALS)
Gravity survey by K.L. Cook and R.L. Stinchcomb
Gravity data reduced in part by the U.S Coast and Geodetic Survey
Gravity contouring by K.L. Cook, R.B. Knittle, and D.R. Mabey
10 0 10 20 30
Scale in Miles
1951
97°
96°
95°
94°
39°
38°
POTTAWOTOMIE
JACKSON
ATCHISON
PLATTE
CLAY
JEFFERSON
LEAVENWORTH
SHAWNEE
WABAUNSEE
WYANDOTTE
JACKSON
Kansas City
Topeka
DOUGLAS
JOHNSON
OSAGE
CASS
LYON
FRANKLIN
MIAMI
Paola
Emporia
COFFEY
ANDERSON
LINN
BATES
GREENWOOD
WOODSON
ALLEN
BOURBON
VERNON
KANSAS
MISSOURI
Nevada
WILSON
NEOSHO
CRAWFORD
BARTON
ELK
MONTGOMERY
LABETTE
CHEROKEE
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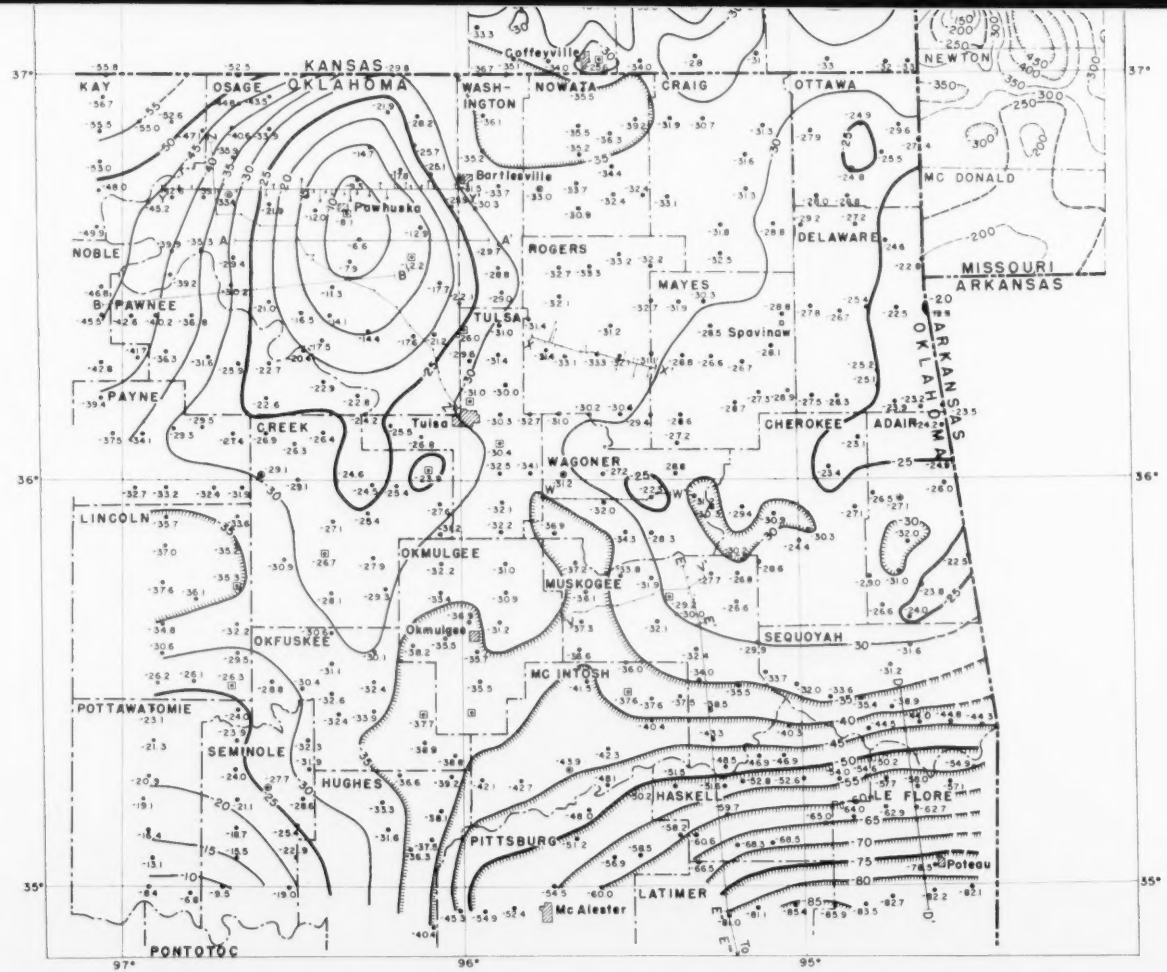


FIG. 2. Bouguer anomalies of gravity in northeastern Oklahoma, southeastern Kansas, and southwestern Missouri. Contour interval 5 milligals. (Contours in Missouri taken from "Gravimetric Map of Missouri," Missouri Geological Survey and Water Resources, 1943.)

gomery County, no symmetrical gravity pattern is observed on either side of the axis, however, and the agreement is therefore probably fortuitous.

The location and general trend of the gravity maximum in Bourbon County agrees in part with the general location and trend of the Bourbon arch. As the anomaly apparently is larger than would be expected from the small structural relief and density contrasts of the sedimentary rocks involved, the agreement in Bourbon County is probably one of chance. In eastern Allen County, moreover, the gravity contours are interpreted to transect the trend of the arch and thus give added support to this contention.

No area within the limits of the survey in Kansas exhibits a known basement relief great enough to cause any of the major anomalies observed. The density contrasts between the basement and sedimentary rocks may be rather small in the surveyed area in Kansas. Woollard's (1943) gravity profile over the Nemaha Granite Ridge in Kansas, lying just west of the surveyed area, failed to show a recognizable gravity anomaly, but Nettleton (1943) reports that in other parts of Kansas more detailed surveys show a fairly definite but local gravity anomaly associated with the ridge. Logue (1954, map) shows a gravity minimum enclosing a small maximum over the ridge in northern Oklahoma.

Thus all the major anomalies within the surveyed area in Kansas are probably caused principally by density contrasts within the basement. The gravity data suggest that the basement in this area is probably of a complex nature and made up of rocks of contrasting properties, with a regional grain striking predominantly west or slightly north of west.

Northeastern Oklahoma

The main regional structural elements in the surveyed area of northeastern Oklahoma are the Ozark uplift, Seneca fault, Hunton arch, and Arkansas basin (Fig. 1). The general regional structural pattern is portrayed by the contours on top of the Mississippian, shown in Figure 1, which indicate the prevailing southeasterly and southerly dips of the Mississippian rocks in the the Arkansas basin area and the prevailing westerly and southwesterly dips throughout most of the remaining part of the surveyed area in Oklahoma.

In the northern part of the surveyed area in Oklahoma, the total thickness of the sedimentary section increases westward from a value of about 1,000 to 2,000 feet in the extreme northeastern part of Oklahoma to nearly 5,000 feet in the west margin of the surveyed area (Fig. 3). In the southern part of the surveyed area in Oklahoma, the total thickness of the Paleozoic sedimentary section increases southward and southeastward along the northern flank of the Arkansas basin to attain a value probably exceeding 22,000 feet in the southern part of the Arkansas basin (Hendricks, 1947, sheet 3, section *CC'*). No wells have penetrated the Atoka formation, of Pennsylvanian age, in the deepest part of the Arkansas basin in Oklahoma, and the depth to which Pennsylvanian and older beds extend beneath the surface is therefore not known (Hendricks, 1939, p. 264).

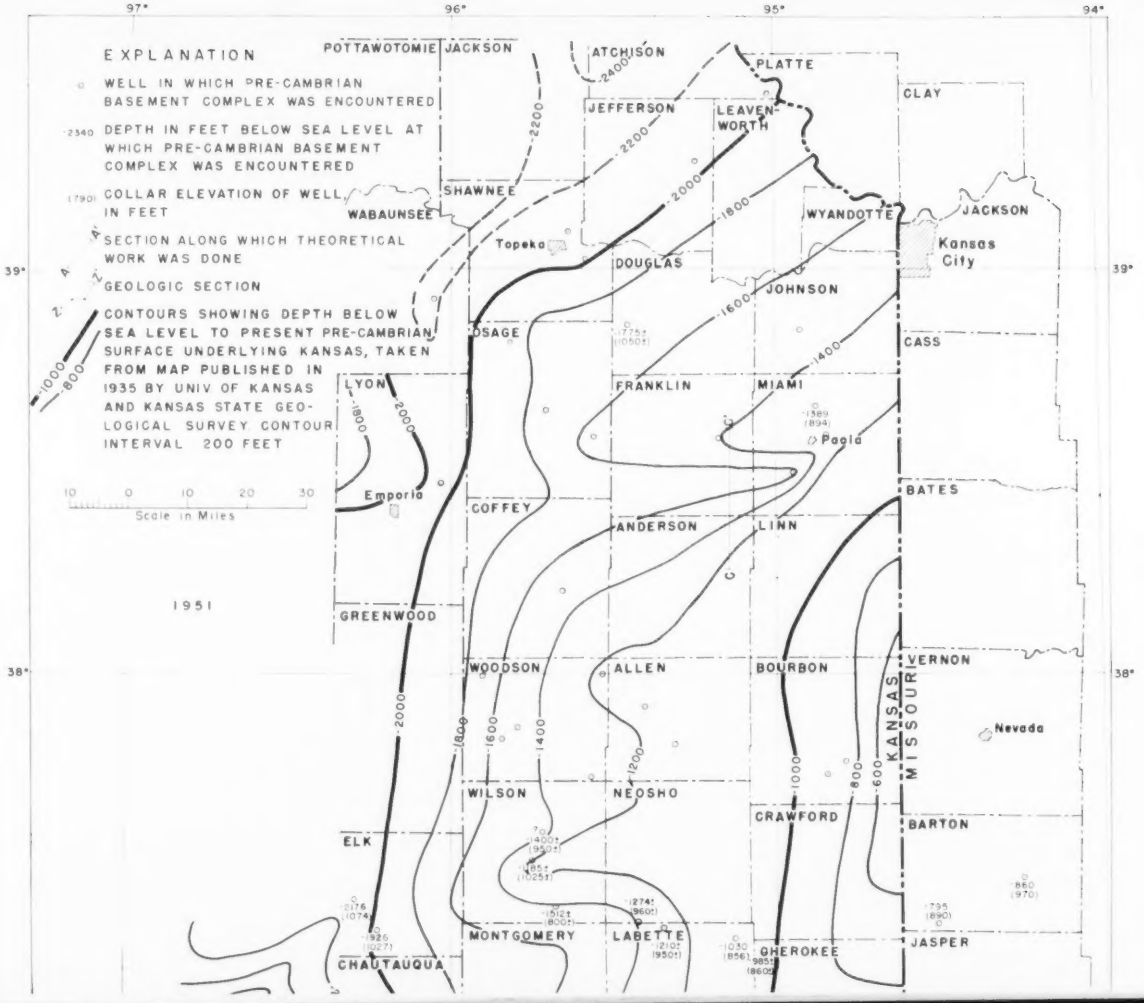
The gravity interpretation in northeastern Oklahoma is based principally on the beliefs (1) that only a small, and perhaps negligible, density contrast exists between the Precambrian basement complex and the dense early Paleozoic rocks that overlie it, and (2) that, according to Nettleton (1940), most of the strong gravity anomalies caused by structure in the sedimentary section in Oklahoma are an expression of the structure in the high-density, pre-Pennsylvanian sedimentary rocks contrasted with the relatively low density of the younger sedimentary rocks. Over most of Oklahoma the density of the rocks from the surface to the bottom of the Pennsylvanian is rather uniform with a value of around 2.2 to 2.4 (Nettleton, 1949) and the density of the Precambrian basement, as well as that of the dolomites and limestones of pre-Pennsylvanian age, including the "Mississippi lime," the Viola limestone, and the Arbuckle group, is probably about 2.65 to 2.70.

The gravity anomalies observed in Oklahoma that are too large to be caused by either basement topography or structure in the sedimentary rocks in the area must be caused principally by density variations in the basement rocks.

Ozark uplift.—There is a rather good correspondence between the gravity and subsurface geology on the southwestern flank of the Ozark uplift, which extends into Oklahoma (Fig. 1). The broad gravity maximum with an indicated closure of about 6 milligals[5] extending through Ottawa, Delaware, Mayes, Cherokee, and Adair Counties and defined roughly by the −30-milligal contour, occurs in an area characterized by a preponderance of dense rocks of pre-Pennsylvanian age near the surface and an absence, or thin section, of rocks of Pennsylvanian age (Miser, 1954; Ireland, 1930). Throughout the area of this gravity high, except possibly for the southern half of Cherokee and Adair Counties, the basement lies at recorded shallow depths of usually less than about 1,000 feet below sea level (Fig. 3). Above the basement here occur principally the limestones and dolomites of the Arbuckle group averaging 600 to 1,000 feet in thickness, which are overlain unconformably by a few hundred feet of limestones of Mississippian age. The only exposures of granite in northeastern Oklahoma occur at Spavinaw, in Mayes County (Fig. 3). The present axis of the Ozark uplift in Oklahoma apparently passes through Adair and Cherokee Counties (Levorsen, 1927, Fig. 13; Cram, 1930, p. 574; Miser, 1954). The gravity high in the northern part of these two counties may be partly a manifestation of the axis; but, because of the shallow depth of the basement, the minor variations of gravity within the broad gravity maximum are probably caused by density variations within the basement. There appears to be a small amount of topographic expression of less than one milligal still in the gravity data in the areas of higher elevation in Delaware County and in the northern parts of Cherokee and Adair Counties.

The broad gravity maximum extends into the southwestern part of Mayes

[5] That closure is actually obtained in Arkansas has been shown by Lyons (1950).


EXPLANATION
WELL IN WHICH PRE-CAMBRIAN BASEMENT COMPLEX WAS ENCOUNTERED
-2340 DEPTH IN FEET BELOW SEA LEVEL AT WHICH PRE-CAMBRIAN BASEMENT COMPLEX WAS ENCOUNTERED
(790) COLLAR ELEVATION OF WELL IN FEET
A A' SECTION ALONG WHICH THEORETICAL WORK WAS DONE
GEOLOGIC SECTION
CONTOURS SHOWING DEPTH BELOW SEA LEVEL TO PRESENT PRE-CAMBRIAN SURFACE UNDERLYING KANSAS, TAKEN FROM MAP PUBLISHED IN 1935 BY UNIV OF KANSAS AND KANSAS STATE GEOLOGICAL SURVEY CONTOUR INTERVAL 200 FEET
10 0 10 20 30
Scale in Miles
1951
97°
96°
95°
94°
39°
38°
POTTAWOTOMIE
JACKSON
ATCHISON
PLATTE
CLAY
JEFFERSON
LEAVENWORTH
SHAWNEE
WABAUNSEE
Topeka
WYANDOTTE
JACKSON
Kansas City
DOUGLAS
JOHNSON
OSAGE
CASS
LYON
FRANKLIN
MIAMI
Paola
Emporia
COFFEY
ANDERSON
LINN
BATES
GREENWOOD
WOODSON
ALLEN
BOURBON
VERNON
KANSAS
MISSOURI
Nevada
WILSON
NEOSHO
CRAWFORD
BARTON
ELK
MONTGOMERY
LABETTE
CHEROKEE
JASPER
CHAUTAUQUA
2400
2200
2000
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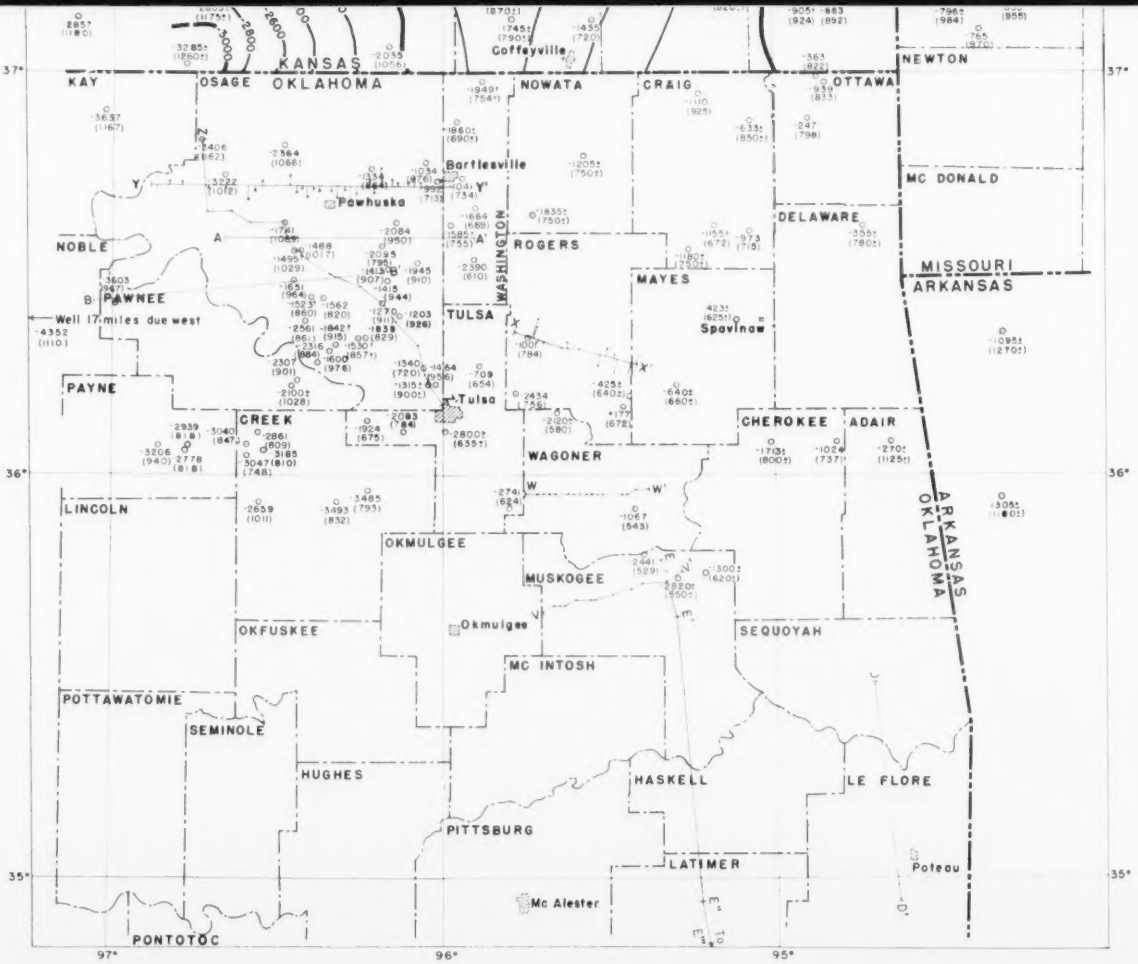

FIG. 3. Map showing wells in which pre-Cambrian basement complex was encountered in parts of Oklahoma, Kansas, Missouri, and Arkansas and contours of depth below sea level to present Precambrian surface underlying Kansas. (Contours taken from map compiled by F. E. Mettner and published in 1935 by University of Kansas and Kansas State Geological Survey; individual well data, originally taken from various sources, have been amended to conform with Precambrian well data recently published by Ireland (1955).

County and the extreme southeastern part of Rogers County, where well data (Fig. 3) indicate a shallow depth to the granite and a thin section of rocks of Pennsylvanian age,[6] into the northeastern part of Wagoner County, where well data indicate a thin section of rocks of Pennsylvanian age (Boyle, 1930, section VII, shown as line *WW'* in Wagoner Co. in Figs. 2 and 3), and into the northern part of Sequoyah County, where the Pennsylvanian rocks are relatively thin (Stone et al., 1930., p. 429; Hendricks et al., 1936, Fig. 3). The Pennsylvanian overlap extends into the southern half of Cherokee and Adair Counties, but the beds of Pennsylvanian age are relatively thin and dip only gently to the south (Cram, 1930, map XLIII and p. 575). Little deep subsurface data are available for the southern parts of Cherokee and Adair Counties, and no Precambrian wells have apparently been drilled here.

The steep gravity gradient along the southwestern and southern margin of the broad gravity maximum corresponds rather well with a pronounced thickening of the rocks of Pennsylvanian age in this area and an accompanying deepening of the dense sedimentary rocks of pre-Pennsylvanian age, as well as a deepening of the basement. In particular this correspondence is shown: (1) in the east central part of Rogers County (Woodruff et al., 1930, cross section XXVII, shown as line *XX'*, Rogers Co. on Figs. 2 and 3); (2) in the extreme northwestern (Fig. 3) and central parts of Wagoner County (Boyle, 1930, section VII, shown as line *WW'* in Figs. 2 and 3); (3) in the north central part of Muskogee County (Soyster et al., 1930, section XXXI, shown as line *VV'*, Muskogee Co., in Figs. 2 and 3); and in the southern half of Sequoyah County (Hendricks et al., 1936, Fig. 3). The shales and sandstones of Pennsylvanian age attain a thickness of about 1,000 feet in the gravity trough at the southern end of the Tulsa-Wagoner County line (Boyle, 1930, section VII, shown as line *WW'* in Figs. 2 and 3) and a thickness of about 2,600 feet in the same gravity trough in west central Muskogee County (Soyster et al., 1930, section XXXI, shown as line *VV'* in Figs. 2 and 3). The rapid thickening of the Pennsylvanian rocks in the southern part of Sequoyah County persists southward into the Arkansas basin proper (Hendricks et al., 1936, Fig. 3).

Seneca fault.—The Seneca fault, which has also been variously called graben, trough, and syncline (Weidman, 1932) is a pronounced linear structural feature; but it is too narrow to be expected to influence the pattern of the regional gravity map in Figure 2.

[6] Although not shown on the map in Figure 3 to avoid confusion, the present thickness of the post-Arbuckle rocks at each given Precambrian well can be readily computed by subtracting the thickness of the Arbuckle and older sedimentary rocks given by Ireland (1946) from the total depth to the Precambrian, which can be obtained from the two values given for each well in Figure 3. This computation results in giving the combined thickness of the rocks of Devonian (?), Mississippian, and Pennsylvanian age for any well occurring in Nowata, Craig, or Ottawa Counties, or in the northern parts of Osage, Washington, Rogers, Mayes, or Delaware Counties, because in these areas the Chattanooga shale of Devonian (?) and Mississippian age rests unconformably on the Arbuckle rocks (White, 1926).

Osage anomaly.—A large gravity maximum with a closure of more than 20 milligals, which in this paper is designated for convenience the "Osage anomaly," extends with a southerly trend through Osage, Pawnee, and Creek Counties for a total distance of about 100 miles.

The gravity anomaly is probably caused principally by a density contrast within the Precambrian basement. A small fraction of the gravity effect may be caused by the present relief of the basement surface, but any such effect is probably smaller than the 5-milligal contour interval on the map in Figure 2.

The Osage anomaly is much too large to be caused by regional structure in the rocks of pre-Pennsylvanian age in this area, which consist principally of westward- or southwestward-dipping beds. The average westward dip across central Osage County is about 39 feet to the mile (Bass, 1942, p. 377). Two geologic cross sections taken across Osage County and beneath the main part of the anomaly—one, in a southeasterly direction as shown by line *ZZ'* in Figures 2 and 3, (Bass,, 1942), and the other in an easterly direction as shown by line *YY'* in Figures 2 and 3 (Coleman, 1930, section XXIII)—show such a very small amount of regional structure in rocks of pre-Pennsylvanian age that any gravity anomaly caused thereby is insignificant in comparison with the large Osage anomaly.[7]

The Osage anomaly is also much too large to be caused principally by topography of the basement rocks in this area, although the general location and pattern of the anomaly agree closely in several respects with the broad features of what Ireland (1946) has designated a "Precambrian highland," known to exist in this general area.[8] The Precambrian highland is a large, irregular-shaped tract characterized mainly by (1) a very uneven basement surface consisting of isolated peaks or ridges of Precambrian rock, which remained as islands until post-Ordovician time and which now protrude into the overlying formations for several hundred to 1,400 feet or more; and (2) a thin column of *essentially flat-lying* Arbuckle rocks, the Arbuckle group, which measures less than 500 feet is most of the area and is absent in a few places, whereas in some areas adjacent to the Precambrian highland the Arbuckle and older rocks are more than 1,500 feet thick (Ireland, 1946; White, 1926). Detailed data concerning the topography and limits of the present Precambrian highland surface are still meager because only a relatively few wells in the area have been drilled to the Precambrian (Fig. 3). The relief of the basement is too great to contour it reliably with the data available in Figure 3. In the central part of the Osage gravity anomaly, the basement lies about 2,500 feet below the earth's surface.

As the essentially flat-lying Arbuckle limestones and dolomites mantle, rather than warp over, the Precambrian highland, little or no gravity effect can

[7] The apex of an anticline with a relief of about 170 feet in rocks of Mississippian age occurs along line *YY'* in Figures 2 and 3 (Coleman, 1930) near the axis of the gravity anomaly north of Pawhuska; but this anticline is much too small to have significance on the regional gravity map.

[8] In a paper published after this manuscript was completed, Ireland (1955) gave the name of "Tulsa Mountains" to this Precambrian highland.

be expected from the topography of the highland surface (see Barton, 1938, p. 378). Nevertheless, the order of magnitude of the largest reasonable gravity effect contributed by the topographic relief of the basement alone in the Precambrian highland area was computed with a two-dimensional graticule (Jung, 1927) along section AA' (Figs. 2 and 3), which extends across the central part of the anomaly for a distance of about 40 miles. The calculations were based on the projection of well data for rather long distances (Fig. 3), and are therefore possibly subject to considerable error, but they are nonetheless probably sufficiently correct for approximate estimates of the gravity effects. The maximum value of the theoretical anomaly is about 3 milligals for an assumed density contrast of 0.15, which is probably larger than the actual density contrast, especially because of the moderately high density of the pre-Pennsylvanian rocks such as the Arbuckle. Detailed gravity work by Jones (1951) in the Owasso area, Tulsa County, Oklahoma, suggests that in this area the density contrast between the basement and sedimentary rocks of pre-Pennsylvanian age is very small (personal communication from V. L. Jones).

Other evidence supports the contention that the Osage anomaly is caused principally by a density contrast within the basement: (1) in several areas the anomaly extends beyond the probable limits of the Precambrian highland; (2) although the gravity gradient west of Pawhuska corresponds well with a persistent westerly regional dip of the top of the basement (Thom, 1936), quantitative determinations with a two-dimensional graticule along section BB', based on meager well data and a density contrast of 0.15, yield a computed gradient several times smaller than the observed value. Some of the gravity effect west of Pawhuska, however, must be due to the structural relief of the rocks of pre-Pennsylvanian age in this region.

The Osage gravity anomaly is of tectonic significance as it overlies, in part at least, an area known to be a positive element that stood comparatively high during Cambrian and part of Ordovician time. That isostatic adjustments have occurred as a consequence of this relatively dense mass within the basement is a possibility that merits further study. The striking coincidence of the circular-shaped gravity maximum with the location of circular-shaped Osage Island[9] suggests the possiblility that a prominent basement swelling or intrusion was active here in late Devonian or early Mississippian time (personal communication from Paul L. Lyons).

Hunton arch.—The area of the Hunton arch was not covered completely by

[9] Osage Island, originally named by Buchanan (1927, p. 1311), and carefully mapped in the subsurface by Leatherock and Bass (1936), designates a circular area lying principally in Osage County but extending partly into Kay County, Oklahoma and Cowley and Chautauqua Counties, Kansas. The area is characterized by an absence of Chattanooga shale, which is deposited widespread in other basin areas in the Midcontinent. Bass (1942, p. 360) gives a maximum thickness of 65 feet to the Chattanooga shale where it is present nearby in the easternmost, southernmost, and locally in the westernmost part of Osage County.

the survey, but the arcuate gravity contours in Seminole and Pottawatomie Counties and the southern part of Lincoln County correspond approximately to the northern and northeastern flanks of the arch. A gravity saddle occurs in Okfuskee County between the northern flank of the gravity maximum associated with the Hunton arch and the southern flank of the Osage anomaly.

The Hunton arch, whose tectonic history is rather complex, is probably cored by granite that is overlain principally by dense rocks of pre-Pennsylvanian age over the central part of the arch (Dott, 1934, p. 595; Dott, 1930, Fig. 11). On the flanks of the arch in the surveyed area, the rocks of pre-Pennsylvanian age, including the dense Arbuckle group and Viola limestone, generally dip rather steeply away from the core and are overlain unconformably by the more gently dipping and lower-density rocks of Pennsylvanian age. The structural relief of the rocks of pre-Pennsylvanian age on the flanks is probably great, and has doubtless been accentuated by faulting (Dott, 1930, Fig. 11; Levorsen, 1930, p. 315; Eardley, 1951, Fig. 132). Along the northeastern flank of the Hunton arch, the total structural relief of the Viola limestone, which can be used in this area as a guide to the structure of all overlying rocks up to the top of the Mississippian, is about 2,000 feet in the southwestern part of Seminole County and the southeastern part of Pottawatomie County, and attains a value of about 4,400 feet or more where the Viola crops out 15 miles south of the Seminole-Pontotoc County line (Levorsen, 1930, p. 314–315; Weirich, 1930, Fig. 110).

The large gravity maximum over the Hunton arch must be due in considerable part to the strong structural relief of the rocks of pre-Pennsylvanian age contrasted with the overlapping and flanking rocks of Pennsylvanian age. A two-dimensional feature would produce a total theoretical gravity effect of about $16\frac{1}{2}$ milligals for the *total* indicated structural relief of 4,400 feet and about $7\frac{1}{2}$ milligals for the 2,000 feet of structural relief present *in the surveyed area only*, provided the reasonable density contrast of 0.3 is assumed between the Pennsylvanian and older rocks in this area. Because the observed gravity effect *in the surveyed area only* is about 20 milligals, and because the strong gravity effect manifests itself much farther north in Seminole, Pottawatomie, and Lincoln Counties than would be expected on the basis of the known subsurface structure associated with the Hunton arch—as portrayed by the structure contours on top of the Mississippian in Figure 1—, a large part of the gravity effect must therefore be attributed also to density contrasts within the basement.

The anomaly is of tectonic significance, not only because it overlies the Hunton arch, but also because it overlies an ancient positive element that almost certainly originated in the Precambrian floor (Van der Gracht, 1931, p. 996). There appears to be a gravity tie between the northern flank of the gravity anomaly associated with the Hunton arch and the southern flank of the Osage anomaly. Logue (1954) draws an orogenic axis between these two anomalies to indicate a late middle Pennsylvanian structural trend in this region. Gravitationally, the anomaly over the Hunton arch apparently indicates a closer tie to

the positive element in Osage County than to the positive element associated with the Ozark dome. It should be emphasized, however, that much of the gravity effect is probably a manifestation of density contrasts within the Precambrian floor.

Arkansas basin.—The Oklahoma part of the Arkansas basin, except for its southwestern part, was covered in the gravity survey. The southernmost gravity stations in Latimer County (Fig. 2) lie immediately north of the Choctaw fault, which defines the northern limit of the Ouachita overthrust (Fig. 1).

The gravity pattern corresponds strikingly well with the pattern of the Arkansas basin in Oklahoma. In particular the decrease in gravity corresponds with the southeasterly and southerly dips of the top of the Mississippian (Fig. 1) and of the basement surface (Thom, 1936) on the northwestern and northern flanks, respectively, of the basin. The gravity trough extending northwestward through the western part of Muskogee County agrees rather well with a tongue of the Arkansas basin that extends north of the basin proper (Hendricks et al., 1936, Figs. 1 and 3). The rapid southward decrease in gravity that occurs in the central part of Sequoyah County, in the southeasternmost part of Muskogee County, and along the southern border of McIntosh County, corresponds very well with a pronounced thickening of the Atoka formation, of Pennsylvanian age, that occurs along this belt (Hendricks et al., 1936, Fig. 3). The rocks of Pennsylvanian age in the Arkansas basin—especially the deeper ones comprising the Atoka formation—continue to thicken pronouncedly to the southeast and south in a manner that conforms well with the gravity contours, and attain a total thickness of at least 13,000 feet in the extreme southeastern margin of the surveyed area south of Poteau, in LeFlore County (Hendricks et al., 1936, Figs. 3, 4, and 5; Hendricks, 1937, p. 1403). The pronounced regional thickening of the rocks of Pennsylvanian age indicates that the basin was warped downward progressively during the time of deposition of these sediments (Hendricks et al., 1936, p. 1355), so that a great structural relief exists in the rocks of pre-Pennsylvanian age (see also Hendricks, 1947). Normal faulting, in which the average eastward-striking fault is downthrown south of its trace, has also accentuated the basin structure to some extent in its northern part (Miser, 1929, plate III, section A; Croneis, 1930, p. 207).

The gravity feature associated with the Arkansas basin is of great regional significance, because the strong negative gravity gradient persists southward to culminate, off the map shown in Fig. 2, in a tremendous gravity minimum over the Ouachita Mountains with a closure of about 70 milligals (Lyons, 1950). The approximate location of the center of the minimum is shown in Figure 1. This anomaly constitutes the strongest gravity *minimum* in the Midcontinent region. About 50 milligals of gravity relief, constituting most of the northwestern flank of this great minimum, are made manifest on the map in Figure 2.

A theoretical gravity profile (shown as line *DD'* in Figs. 2 and 3), 37 miles in length, was taken through the southern part of Sequoyah County and the north-

ern part of LeFlore County. The profile lies in the area of steep gravity gradient, which also coincides with the belt of great structural downwarp. On the basis of the isopach maps given by Hendricks, Dane, and Knetchel (1936, Figs. 3, 4, and 5) for the rocks of Pennsylvanian age in this area, the approximate total thickness of the rocks of Pennsylvanian age was assumed to be 2,000 feet at the north end of profile *DD'* and 13,000 feet at the south end of the profile. As only the order of magnitude of the gravity effect was desired, the inferred structural relief of 11,000 feet on top of the pre-Pennsylvanian rocks was assumed to be linear between the ends of the profile, thus making an average southerly regional dip of about 300 feet to the mile, or about 3°. This regional dip agrees with that assigned by Levorsen (1927, p. 665) to the Wilcox formation, of Ordovician age, in the McAlester-Atoka area nearby. Based on these assumptions, and using a two-dimensional graticule, the average theoretical gravity gradient along profile *DD'* is about one milligal per mile for an assumed density contrast of 0.3, and about $\frac{2}{3}$ milligal per mile for an assumed density contrast of 0.2. The observed gravity gradient of about $1\frac{1}{3}$ milligals per mile along the profile requires a density contrast of 0.4 between the Pennsylvanian and older rocks with the assumptions made. If a density of 2.7 were assumed for the rocks of pre-Pennsylvanian age, including the basement complex , an average density of 2.3 would be required for the rocks in the Pennsylvanian section in the Arkansas basin to give the gravity gradient observed. On the basis of the increasing density with depth for *shales* of Pennsylvanian age in northeastern Oklahoma (Athy, 1930, Fig. 2) and on the basis of the small amount of published data on the densities of the rocks of Pennsylvanian age in the Arkansas basin,[10] an average density of 2.4—or perhaps even 2.5—for the Pennsylvanian rocks would seem more reasonable than 2.3 for the relatively great depths involved in this area.

The observed gravity effect in the Oklahoma part of the Arkansas basin is probably caused principally, though perhaps not entirely, by the structural downwarp of the basement and of the sedimentary rocks of pre-Pennsylvanian age that has resulted in a pronounced horizontal density contrast between these older rocks and the rocks of Pennsylvanian age that filled the basin during the downwarping. In the deepest part of the Arkansas basin in Oklahoma, a significant contribution to the gravity effect is probably caused by density contrasts within the basement unless the thickness of the sediments of Pennsylvanian age exceeds substantially (by as much as 3,000 feet, if a density contrast of 0.3 is assumed) the estimate of about 13,000 feet, or unless the pre-Pennsylvanian limestone-dolomite rocks grade into a shale-sandstone facies in the deepest part

[10] The average density of unweathered *sandstones* of Pennsylvanian age at the surface in the Arkansas part of the Arkansas basin, as determined by Branner (1937, p. 72) from 63 samples, is 2.43. Along profile *DD'* the thickness of the Atoka formation is generally more than twice as thick as the combined thickness of all the overlying beds (Hendricks, Dane, and Knetchel, 1936, Figs. 3, 4, and 5). The average density of 51 samples of *sandstone* in the Atoka at the surface in the Arkansas part of the Arkansas basin is 2.41 (Branner, 1937, p. 72).

of the Arkansas basin. Because the Atoka formation has not been completely penetrated by the drill in the deepest part of the Arkansas basin where the downwarping was a maximum (Hendricks, 1939, p. 264), there is a strong possibility that one or both of these latter conditions exist. A Pennsylvanian section substantially thicker than 13,000 feet in the deepest part of the Arkansas basin is the favored interpretation; yet the possibility of a facies change in the pre-Pennsylvanian rocks in the deepest part of the Arkansas basin also exists.

ACKNOWLEDGMENTS

Joseph A. Sharpe, Vice-President of the Frost Geophysical Corporation, prior to his death, helped the writer with several technical suggestions. The friendly cooperation of A. J. Hoskinson and G. R. Shelton, of the U. S. Coast and Geodetic Survey, is hereby acknowledged. R. L. Stinchcomb, also of the U. S. Coast and Geodetic Survey, ably assisted the writer in operating the gravimeter in the field. Appreciation is expressed to the office personnel of the U. S. Coast and Geodetic Survey for reducing the gravity data to free-air anomaly values. Helpful assistance in compilation of data and maps was given by D. L. Endsley, R. B. Knittle, H. E. Kuehn, D. R. Mabey, and C. K. Moss, U. S. Geological Survey. Information concerning the regional geology was given by the following: H. A. Ireland, University of Kansas; Wallace Lee and Hugh D. Miser, U. S. Geological Survey. Valuable advice and data concerning many Precambrian wells shown in Figure 3 were given by H. A. Ireland. Paul L. Lyons, of the Sinclair Oil and Gas Company, gave valuable suggestions concerning the interpretation. Responsibility for all statements, however, rests solely with the writer.

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MINIMUM VARIANCE IN GRAVITY ANALYSIS

PART II: TWO-DIMENSIONAL

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ABSTRACT

The principles developed in Part 1 apply whether the data points are located on a line or distributed over a plane. The practical calculation problem, however, is more complicated in two dimensions than in one. There are two steps: (1) deciding what terms to keep in the polynomial approximation; (2) estimating second vertical derivatives and the like on the basis of the chosen approximation. For (1) we can use two-dimensional orthogonal polynomials; but complete tables of them would be bulky, and therefore several alternative procedures are outlined. For (2) we can easily derive "best" estimation formulas by the minimum-variance method; but these usually involve many-digit multipliers, and therefore "near-best" coefficients, with fewer digits, are also derived. The specific problems solved here start with uncorrelated data at points of a square grid. In practice, data are taken at irregularly distributed stations: then the minimum-variance principle and orthogonalization still apply, but the calculations are more complex, and grid values computed from the station values are correlated.

1. INTRODUCTION

Scope of Part 2

Part 1 (Brown, 1955) illustrated the minimum-variance principle by applying it to data taken along a line; Part 2 applies it to data taken over a plane. The statistical theory requires only trivial changes. The emphasis in Part 2 will therefore be not on statistical principles, but on the difficulties peculiar to the two-dimensional (as opposed to one-dimensional) situation. These difficulties are the following.

First, in one dimension it is practical to compute complete tables of orthogonal polynomials; in two dimensions the labor would be enormous and the tables impractically bulky.

Second, in one dimension it is a simple problem to choose an adequate approximating polynomial: we merely look for a suitable cutting-off point in the sequence $1, x, x^2, \cdots$. In two dimensions, we must choose a set of low-degree terms from

$$\left.\begin{array}{cccc} 1 & y & y^2 & \cdots \\ x & xy & xy^2 & \cdots \\ x^2 & x^2y & x^2y^2 & \cdots \\ \cdots & \cdots & \cdots & \cdots \end{array}\right\} \qquad (1\text{-}1)$$

For instance, we might decide to keep the terms

$$\begin{array}{ccc} 1 & y & y^2 \\ x & xy & \\ x^2 & & \end{array} \qquad (1\text{-}2)$$

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or the terms

$$\begin{array}{|ccc|} \hline 1 & y & y^2 \\ x & xy & xy^2 \\ x^2 & x^2y & x^2y^2 \\ \hline \end{array} \tag{1-3}$$

Third, for comparable precision, the two-dimensional calculation may be expected to be more laborious than the one-dimensional.

These differences make it important to develop efficient methods, and to look for tricks that will shorten the calculations.

Complete vs Routine Analysis

In estimation of even vertical derivatives, the main purpose of a complete orthogonal-polynomial analysis is to estimate the error variance and to decide how many terms to keep in the approximating polynomial. There is no need to do this for every point at which the derivatives are to be estimated; it is sufficient to do it for a representative sample of such points. Once the proper number of terms has been decided, all that is needed for the routine analysis is a formula for calculating estimates of the derivatives directly from the data. Such a formula can be derived by direct application of the minimum-variance principle.

Practically, therefore, our problem breaks into two parts: (1) How can we analyze representative samples to decide what polynomial approximation to use? (2) After that decision, how can we do a routine analysis of a large area without either excessive labor or excessive error? Of the following sections, Section 2 relates especially to part (1) of the problem, and Sections 3–5 especially to part (2).

Outline

Section 2 deals with orthogonal functions in two dimensions; especially with methods of using tables of limited extent, and with the problem of choosing the right polynomial approximation.

Section 3 derives best coefficients for second vertical derivatives and for other quantities, for various arrays of points, on the assumption that a polynomial of second or third degree in x and y is adequate.

Section 4 derives best coefficients for second and fourth vertical derivatives and for other quantities, on the assumption that a polynomial of fourth or fifth degree in x and y is adequate.

Section 5 replaces the best coefficients of Section 4 with near-best coefficients of fewer digits. This is a practical device for shortening the calculation time in routine analysis.

Section 6 applies the theory and tables to an illustrative numerical example.

Section 7 abandons the simplifying assumption that the independent data points are conveniently arranged; it considers measurements taken at irregularly located stations.

Theoretical Model

The theoretical model of Part 1 requires only the following change. The symbols $g_1, g_2, \cdots, g_n$ now represent observed vertical intensities at n points (x_1, y_1), $(x_2, y_2), \cdots, (x_n, y_n)$ of a horizontal plane (the earth's surface); instead of (x_i, y_i), we henceforth write the two-dimensional vector $\mathbf{r}_i$. The symbols u_{r1}, $u_{r2}, \cdots, u_{rn}$ represent the values, at the same points, of a known function $u_r(\mathbf{r})$ of the two coordinates (x, y). (The functions $u_0(\mathbf{r})$, $u_1(\mathbf{r}), \cdots$ may be, for instance, $u_0 = 1$, $u_1 = x$, $u_2 = y$, $u_3 = x^2$, $u_4 = xy$, $u_5 = y^2, \cdots$.) Similar statements hold for the symbols η_i, $\hat{\eta}_i$, etc.

With this interpretation of the symbols, the David-Neyman theorem holds as before; for it is independent of any geometrical meaning of i and r. The same is true of the properties of orthogonal functions. Up to this point it is immaterial in what order the functions u_r are numbered. (We may, if we wish, take $u_0 = 1$, $u_1 = x$, $u_2 = xy$, $u_3 = y$, $u_4 = x^2$, $u_5 = x^2y$, $u_6 = x^2y^2$, $u_7 = xy^2$, $u_8 = y^2$.) No matter what terms are dropped from the expansion formula (5–3) of Part 1, the result is the best approximation attainable by fitting g_i to the terms that are kept, by the minimum-variance criterion.

But if the choice of terms to be kept makes no sense physically, neither will the resulting approximation. In approximating a gravitational field with a polynomial, we normally try a group of terms such as (1-2) or (1-3), rather than one, for instance, that omits 1 and includes x^6y^6. In particular cases, however, there may be good physical reason for omitting specified low-degree terms. Statistical theory cannot tell us which terms to omit; but if physical theory suggests omission of a term, statistical theory can tell us how to test the hypothesis that that term is zero.

An important physical property of our model is that in three dimensions, the true intensity η is a harmonic function throughout the region of observation. It follows that the operator $\partial^2/\partial z^2$, acting on η, is equivalent to $-\partial^2/\partial x^2 - \partial^2/\partial y^2$. We take z positive downward, and $z = 0$ in the observation plane. Then since we can estimate horizontal derivatives of η in the plane $z = 0$, we can also estimate even vertical derivatives at points of this plane. By combining these, we can estimate the mean of the upward- and downward-continued intensities,

$$\eta^*(x, y, z) = \tfrac{1}{2}\eta(x, y, z) + \tfrac{1}{2}\eta(x, y, -z); \qquad (1\text{-}4)$$

this is just the even part of the Taylor's series for η in powers of z. For emphasizing local anomalies, η^* is as useful as the downward-continued intensity $\eta(x, y, z)$. (To estimate $\eta(x, y, z)$ itself, we must estimate both η^* and the upward-continued intensity $\eta(x, y, -z)$ and then use (1–4). The estimation of $\eta(x, y, -z)$ requires integration over the infinite plane $z = 0$ and is outside the scope of this article.)

Notation for Arrays

For arrays of points chosen from a square grid, we shall sometimes use the notation illustrated in Fig. 1. We choose as origin the point where $\eta_{zz} (= \partial^2\eta/\partial z^2)$

etc. are to be estimated; we number this point 0. In accordance with the symmetry of the quantities to be estimated, we always use an array of data points symmetric about the x-axis, the y-axis, and the 45° lines. Every point in the first half-quadrant ($x \geqq y \geqq 0$) determines a group of 4 or 8 points with the required symmetry, and by combining such groups we can get all possible arrays with the required symmetry. We number the groups by numbering their generating points in the first half-quadrant, in the order shown in Fig. 1(a); the numbering can be

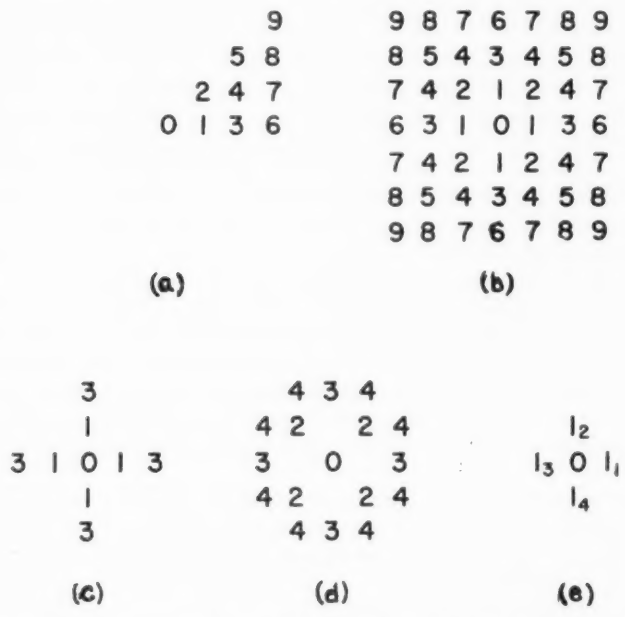


FIG. 1. Notation for groups of points and for arrays. (a) Numbering of points in the representative half-quadrant. (b) Numbering of points without distinction within groups. (c) The array 013. (d) The array 0234. (e) Complete numbering of points for the array 01.

extended to any number of points. Then for many purposes it is sufficient to identify each point merely by its group number, as in Fig. 1(b). We can describe any array by listing the group numbers of its component groups: Fig. 1(c) shows the array 013, and Fig. 1(d) shows the array 0234. If we wish to distinguish the 4 or 8 points within a group, we may add a subscript as in Fig. 1(e); this gives the order of the point in a counter-clockwise trip around the origin, with point 1 always on the x-axis.

We choose the units so that the grid interval is 1; then for any point of any array chosen from the grid, x_i and y_i are integers. On going over from the general

statistical theory to specific arrays, we shall sometimes replace the subscript i, which identifies a single point, by a subscript p, which identifies the group according to the code of Fig. 1. All the points of a group p are at the same distance r_p from the origin.

2. ORTHOGONAL FUNCTIONS IN TWO DIMENSIONS

Orthogonal Polynomials in General

For a given array of n points, we can choose from the set of functions (1-1) n that are linearly independent. We can in fact choose them in an infinite number of ways; for reasons sketched in Section 1, we normally try to choose them according to a scheme such as (1-2) or (1-3). For particular arrays, however, we shall have to leave gaps in such a scheme in order to get linearly independent functions. For instance, if every point of the array is on either the x-axis or the y-axis, then only the top row and left column of (1-1) are useful. Again, if all the points lie on a circle of radius R, then the three functions 1, x^2, and y^2 satisfy the linear relation $R^2 \cdot 1 + (-1) \cdot x^2 + (-1) \cdot y^2 = 0$ at all the points, and therefore only two of these functions (or two linear combinations of them) are useful.

By the orthogonalization process described in Part 1, equations (5–10), we can generate from the set (1-1) an orthogonal set. It will consist of n polynomials in x and y. If linearly dependent functions are inadvertently included in the set (1-1), the orthogonalization process will discover them. For instance, consider the array 4 (Fig. 1) consisting of 8 points on the circle $x^2+y^2=5$: If we start with $U_0=1$, $U_1=x^2$, $U_2=y^2$ and orthogonalize, we get $u_0=1$, $u_1=2x^2-5$, $u_2=0$ at every point of the array; therefore U_2 must be replaced by a function of higher degree.

It is impractical to compute orthogonal polynomials for all the arrays that might be useful. In lieu of this, the following procedures are available.

Rectangular Arrays

For a rectangular array, with n rows of m points each, the orthogonal polynomials are of the form

$$u_{rs}(\boldsymbol{r}) = u_r^{(m)}(x) \cdot u_s^{(n)}(y), \tag{2-1}$$

where the $u_r^{(m)}$'s are one-dimensional orthogonal polynomials for m points, and where the $u_s^{(n)}$'s are one-dimensional orthogonal polynomials for n points.

Let g_{mn} be the observed intensity at the point $\mathbf{r}_{mn}=(m, n)$. Then the expansion theorem of Part 1, equation (5–3), becomes in two-dimensional notation

$$g_{mn} = \sum_{r=0}^{m-1} \sum_{s=0}^{n-1} c_{rs} u_{rs}(\mathbf{r}_{mn}). \tag{2-2}$$

The coefficients can be found in two steps, each one-dimensional: (1) expand g_{mn} in orthogonal polynomials in x, for each value of y; (2) expand each of the co-

efficients in (1) in orthogonal polynomials in y. The order—x and then y, or y and then x—is immaterial. DeLury (1950, p. 10–13) illustrates a systematic procedure for carrying out the expansion and for deciding what terms to keep.

Once the coefficients c_{rs} have been found and the nonsignificant ones rejected, any significant derivatives can be estimated by differentiating (2-2), with nonsignificant terms omitted, and inserting the c_{rs}'s. This requires tables of derivatives of orthogonal polynomials (Part 1, Tables 1–3; Brown and Dempsey, 1950). Another method is to calculate the estimated intensity, $\hat{\eta}_{mn}$, by substitution in (2-2) with nonsignificant c_{rs}'s omitted, and then to differentiate the resulting function by methods of numerical calculus. In the differentiation, enough points must be used in Bickley's formulas (Southwell, 1946, p. 229–237) or enough differences in the differentiation-by-differences formulas (Whittaker and Robinson, 1944, p. 62–65; Milne, 1949, p. 191–193) to make the differentiation exact for the polynomial $\hat{\eta}$.

Symmetric Arrays

For estimation of even vertical derivatives at the central point o, we choose symmetric arrays of the type illustrated in Fig. 1. For such arrays, the only functions that contribute to the estimated quantity are those that are even in x and y and symmetric between x and y. (We call a function $f(x, y)$ "symmetric between x and y" if $f(y, x)=f(x, y)$; "antisymmetric between x and y" if $f(y, x)=-f(x, y)$.) These are:

$$\left.\begin{array}{l} 1; \\ x^2+y^2; \\ x^4+y^4,\ x^2y^2; \\ x^6+y^6,\ x^4y^2+x^2y^4; \end{array}\right\} \qquad (2\text{-}3)$$

and so on. The functions (2–3) are automatically orthogonal to functions that differ from them by being odd in x or in y or antisymmetric between x and y, or by any combination of these properties. We may therefore orthogonalize the set (2-3) by itself and, for any set of data, compute only the coefficients of the orthogonal polynomials generated by this set. This gives us all the significant coefficients that are useful for the particular estimation problem we are solving. It does not, however, give us as reliable an estimate of the error variance as would a complete analysis.

If we use these symmetrized polynomials to calculate coefficients c_r from the observed intensities, we are in effect doing the following: (1) calculating the average $\bar{g}_p=n_p^{-1}\sum_i g_{pi}$ of the observed intensities g_{pi} at the n_p points p_i of each symmetric group p; (2) fitting this average, by least squares, to a polynomial $\hat{\eta}_p$ of the symmetry described above. The sum of squares Q thus minimized is the sum over the individual points with equal weights, or over the groups with weights

n_p, of the squared deviations $\bar{g}_p - \hat{\eta}_p$: that is, $Q = \sum_p n_p(\bar{g}_p - \hat{\eta}_p)^2$. Let $N+1$ be the number of points in the array; let $n'+1$ be the number of groups, and therefore also the number of possible independent orthogonal polynomials of the required symmetry; and let $k+1$ be the number of terms retained in $\hat{\eta}_p$. Then of the $N+1$ available degrees of freedom, $n'+1$ are used and $N-n'$ are disregarded. Of the $n'+1$ degrees of freedom that are used, $k+1$ are used to estimate parameters and $n'-k$ to estimate the error.

These principles may be used to derive the following formulas, which replace (4-13) and (5-9) of Part 1: $s^2 = Q_0/(n'-k)$, $Q_0 = \sum_p n_p \bar{g}_p^2 - \sum_{r=0}^{k-1} S_r c_r^2$.

Tables 1 and 2[1] give the symmetrized orthogonal polynomials for two arrays: the 49-point square array 0123456789 (notation of Fig. 1) and the 25-point array 0123569. The latter contains those points of the former that lie on a coordinate axis or a 45° line.

Table 1, for the 49-point array, was calculated from one-dimensional tables. The functions tabulated are

$$\left.\begin{aligned} u_{rr}(\boldsymbol{r}) &= \xi'_r(x)\xi'_r(y), \\ u_{rs}(\boldsymbol{r}) &= \xi'_r(x)\xi'_s(y) + \xi'_s(x)\xi'_r(y) \text{ for } s \neq r; \end{aligned}\right\} \tag{2-4}$$

ξ'_r is read from tables of orthogonal polynomials for 7 points. The entries are exact.

Table 2, for the 25-point array, was calculated by orthogonalizing the functions

$$\left.\begin{aligned} U_0 &= 1, \\ U_1 &= x^2 + y^2, \\ U_2 &= x^4 + y^4, \\ U_3 &= x^2y^2, \\ U_4 &= x^6 + y^6, \\ U_5 &= x^4y^2 + x^2y^4, \\ U_6 &= (x^2 + y^2)^4. \end{aligned}\right\} \tag{2-5}$$

The first four orthogonalized functions u_r are given by

$$\left.\begin{aligned} u_0 &= 1, \\ u_1 &= 25\,U_1 - 168, \\ 300\,u_2 &= 64{,}925\,U_2 - 3{,}054{,}072 - 24{,}929\,u_1, \\ 64{,}925\,u_3 &= 261{,}452{,}975\,U_3 - 4{,}099{,}582{,}648 \\ &\quad - 46{,}785{,}686\,u_1 - 112{,}800\,u_2; \end{aligned}\right\} \tag{2-6}$$

[1] Permanently useful tables are numbered 1, 2, · · · and are assembled at the end of this article. Tables useful only in the discussion of the specific numerical examples of Section 6 are numbered 6-1, 6-2, · · · and are placed near the corresponding parts of the discussion.

the entries in Table 2 are exact. The remaining three functions have not been computed. In the applications intended, they are of no value except for verifying that omitted terms are nonsignificant; and this can be done more easily by comparing the estimate of variance s^2 with an independent one based, say, on one-dimensional analysis of linear arrays of points.

Possible Procedures for Arbitrary Arrays

Suppose that we wish to use an array, such as 0136, for which we have no tables of orthogonal polynomials. How can we estimate the error level and decide what degrees in x and y to keep?

Use of Linear Arrays.—One method is to do a one-dimensional orthogonal-polynomial analysis on several independent sample lines of points along the x-axis and along the y-axis. If the linear arrays have the same spacing and extent as representative lines across the array to be used, this analysis will determine how far to go along the top row and down the left column of (1-1). We may now complete the set of functions in the manner (1-2), on the assumption that the last significant terms are those of a definite degree in x and y jointly.

Use of Substitute Arrays.—Another method is to do a two-dimensional orthogonal-polynomial analysis on another array of comparable extent, for which tables have been computed, and then to make allowance for differences between the two arrays. For instance, if the array to be used is 0136, we can analyze representative 7 by 7 squares. If x^4 and y^4 are not significant in the 7 by 7 square, they can safely be omitted in array 0136; the estimation formula will then be based on the terms 1 and x^2+y^2. If, however, x^4+y^4 and x^2y^2 are significant in the 7 by 7 square, then array 0136 is a poor choice, for it cannot detect the term x^2y^2.

Computation of Special Tables.—If an array is to be used regularly, the appropriate orthogonal polynomials can be calculated for this array. The method is that described in Part 1, equations (5-10), and just illustrated in Table 2 and equations (2–6).

Least-Squares Analysis without Orthogonalization.—For methods of this sort in one dimension, see Guest (1950, 1952, 1953) and Hayes and Vickers (1951). In two dimensions, there is the difficulty that the functions (2-3) do not form a one-dimensional sequence of steadily decreasing presumptive importance. Shall we arrange the fourth-degree terms in the order x^4+y^4, x^2y^2 or in the order x^2y^2, x^4+y^4? Or shall we combine them into $r^4=(x^2+y^2)^2$ and $r^4\cos 4\theta=x^4-6x^2y^2+y^4$? This question may still bother us when we use orthogonal functions; but then we can try various combinations of the fourth-degree terms without thereby changing the coefficients of the lower-degree terms.

Other Orthogonal Functions

Instead of starting with the set of functions (1-1), we can start with any set of functions linearly independent with respect to the chosen array of points. The

trigonometric functions used in one-dimensional Fourier analysis of data at n uniformly spaced points are orthogonal, and they lead directly to two-dimensional orthogonal functions for an n-by-m rectangle.

3. BEST SECOND- OR THIRD-DEGREE COEFFICIENTS

The Problem

We suppose that $\eta(x, y, 0)$ can be approximated well with a polynomial of degree 2 or 3 in x and y jointly. We choose an array of points with the symmetry illustrated in Fig. 1. The quantities ω to be estimated are the second vertical derivative $\eta_{zz}(0, 0, 0)$ at the central point; the intensity $\eta(0, 0, 0)$ at the central point; and the mean of the upward- and downward-continued intensities, $\eta^*(0, 0, z) = \eta(0, 0, 0) + (z^2/2)\eta_{zz}(0, 0, 0)$. Since fourth-degree terms are not significant in η, they cannot be estimated in η^*; the estimate $\hat{\eta}^*$ will be reliable only at small z. The estimated intensity at the central point, $\hat{\eta}(0, 0, 0)$, is a smoothed or graduated value.

We shall be concerned mainly with the estimation of $\eta_{zz}(0, 0, 0)$.

Solution by the Minimum-Variance Method

Since tables of orthogonal polynomials may not be available for the array chosen, we apply the minimum-variance principle directly. We seek an estimate of ω of the form

$$w = \sum_p a_p(g_{p1} + g_{p2} + \cdots), \tag{3-1}$$

where g_{pq} is the observed intensity at point p_q of group p. The variance of w is

$$\sigma_w^2 = \sigma^2 \sum_p n_p a_p^2, \tag{3-2}$$

where n_p is the number of points (1, 4, or 8) in group p. The variance is to be minimized under the restriction that (3-1) is to be exact, in the absence of experimental error, when $g = 1$ and when $g = x^2 + y^2 = r^2$. Terms linear and cubic in x or in y can be ignored because of the symmetry.

The method of Lagrangian multipliers, illustrated in Section 3 of Part 1, gives for $w = \hat{\eta}_{zz}(0, 0, 0)$

$$a_p = (4/D)\left(\sum_q n_q r_q^2 - n r_p^2\right), \tag{3-3}$$

with

$$D = n\sum_q n_q r_q^4 - \left(\sum_q n_q r_q^2\right)^2. \tag{3-4}$$

With these a_p's, the variance (3-2) is

$$\sigma_w^2 = \sigma^2 \cdot 16n/D. \tag{3-5}$$

For $w = (0, 0, 0)$,

$$a_p = (1/D)\left(\sum_q n_q r_q^4 - r_p^2 \sum_q n_q r_q^2 \right), \tag{3-6}$$

$$\sigma_w^2 = \sigma^2 \cdot \sum_p n_p r_p^4 / D, \tag{3-7}$$

with D as before.

Coefficients for $w = \hat{\eta}^*(0, 0, z)$ can be found by substituting the formulas (3-1) for $\hat{\eta}(0, 0, 0)$ and for $\hat{\eta}_{zz}(0, 0, 0)$ in the formula $\bar{\eta}^*(0, 0, z) = \eta(0, 0, 0) + (z^2/2)\bar{\eta}_{zz}(0, 0, 0)$.

Comparison of Coefficients

For practical reasons, we may consider using coefficients that are not as good as the best coefficients (3-3) or (3-6). Such coefficients can be assessed by substituting them in (3-2) and comparing the result with (3-5) or (3-7). This method will be illustrated at the end of this section and in Section 5.

Comparison of Arrays

It is also important to compare *different arrays*. In the variance of $\bar{\eta}_{zz}(0, 0, 0)$, two factors are important: the scale of an array and its geometric form. In $\eta(0, 0, 0)$ the scale has no effect. The following discussion relates to $\bar{\eta}_{zz}(0, 0, 0)$.

Scale.—Consider the two geometrically similar arrays 012 and 035: since each r_p for the latter is twice the corresponding r_p for the former, σ_w/σ for the latter is (by equations (3-4)–(3-5)) one-quarter as large as σ_w/σ for the former. In general, for geometrically similar arrays, σ_w/σ is inversely proportional to the square of a distance characteristic of the array. If fourth-degree terms are still negligible for the larger array 035, it is a better array to use than 012. But the array 035 would be labeled 012 in a grid with twice the original spacing. Therefore if 012 is to be used, the grid should have the largest spacing compatible with neglect of fourth-degree terms. If such a grid gives less than the desired density of w-values, then array 023 or 035 should be used instead of 012, and the grid should have the largest spacing compatible with neglect of fourth-degree terms for the array actually chosen.

Geometric Form.—To examine this, we must remove the scale effect by multiplying σ_w/σ by the square of some characteristic distance. We choose for this purpose the mean square distance of the points from the origin,

$$\overline{r^2} = \sum_p n_p r_p^2 / n. \tag{3-8}$$

This gives a criterion

$$\mu = (\sigma_w/\sigma)\overline{r^2} \tag{3-9}$$

for comparing arrays of different forms.

The criterion is not highly sensitive to the choice of the characteristic distance. For instance, the largest r^2 of the array can be used instead of the mean; the resulting criterion μ' ranks the arrays in almost the same order as does μ.

Tables of Best Coefficients

Table 3 lists best coefficients for estimating the second vertical derivative $\eta_{zz}(0, 0, 0)$. The arrays, mostly 9-point, are arranged in order of increasing μ, i.e. of decreasing merit. The coefficients for each array are given as numerators $(D'a_p)$ to be divided by a common denominator (D'). Both criteria μ and μ' are listed as well as σ_w/σ. By the μ-criterion, the best arrays are those with a broad spread of r_p-values and with several points at each r_p; this permits reliable determination of the slope of a curve $\eta = A + Br^2$ with respect to r^2. Thus the best 9-point array is 016, with four points on a circle of radius 3 and four points on a circle of radius 1; the worst 9-point array is 04, with eight points on a single circle. The 8-point array 13 is better than the 9-point array 04, and its multipliers are all either $+1$ or -1; this is an advantage in routine calculations. In second-degree formulas the angular distribution of the points is not important.

Table 4 lists best coefficients for estimating the intensity at the central point, $\eta(0, 0, 0)$.

Table 5 lists best coefficients for estimating the mean of the continued intensities at distance $+1$ and -1 from the observation plane, $\eta^*(0, 0, 1)$.

Tables 4 and 5 cover only a few arrays because, with fourth-degree terms not significant, $\bar{\eta}(0, 0, 0)$ and $\bar{\eta}^*(0, 0, z)$ are not very useful.

Comparison with Other Coefficients

In Part 1, Section 3, coefficients for $\bar{\eta}_{zz}(0, 0, 0)$ were derived for arrays 013 and 0136 by estimating η_{xx} and η_{yy} separately, with one-dimensional formulas. These coefficients gave $\sigma_w/\sigma = 0.857$ for array 013 and $\sigma_w/\sigma = 0.337$ for array 0136; the coefficient for points 3 of array 0136 was zero. The two-dimensional coefficients, based on consistent treatment of the central point, give 0.824 for array 013 and 0.326 for array 016 or 0136. (Formula (3-5) gives 0.3263 for array 016, 0.3257 for array 0136.)

Elkins (1951, p. 37) gives two sets of coefficients for $\bar{\eta}_{zz}(0, 0, 0)$ for array 0124. His first set, his equation (13), assumes the value of g at the origin to be exact; on the present assumption of equal variances for all g_i's, these coefficients give $\sigma_w/\sigma = 1.1$. His second set, his equation (14), assumes equal variances for the *average* g of each of the four groups 0, 1, 2, 4; on the present assumption of equal variances for *individual* g_i's these coefficients give $\sigma_w/\sigma = 0.66$. The "best" coefficients give $\sigma_w/\sigma = 0.51$. They are actually best, of course, only if the variances of individual g_i's are in fact equal. Elkins' variance assumptions are not stated explicitly but are implied by the weights assigned to the various averages in his least-squares calculation (Arley and Buch, 1950, p. 182).

Any superiority of the present coefficients to earlier ones, such as those of

Elkins, usually is small, shows up only statistically, and is conditional on the validity of the assumptions made in regard to the behavior of the errors. Nobody who has done extensive calculations with such coefficients would be justified in doing them over with the new ones. In new calculations, however, statistical theory dictates a preference for the new coefficients, if the actual behavior of the errors is believed to be approximately in accordance with the assumptions made here.

4. BEST FOURTH- OR FIFTH-DEGREE COEFFICIENTS

The Problem

We now suppose that $\eta(x, y, 0)$ requires a polynomial of degree 4 or 5 to approximate it satisfactorily. We must use an array with enough points to permit evaluation of the coefficients of 1, x^2+y^2, x^4+y^4, and x^2y^2. The quantities to be estimated are the second and fourth vertical derivatives at the central point 0, the graduated intensity at 0, and the fourth-degree approximation to $\eta^*:\eta^*(0, 0, z) = \eta(0, 0, 0)+(z^2/2)\eta_{zz}(0, 0, 0)+(z^4/24)\eta_{zzzz}(0, 0, 0)$.

We shall select the smallest array likely to give satisfactory precision, and shall calculate best coefficients for it. We shall also calculate best coefficients for the 25-point array 0123569 and for the 49-point square array.

Selection of a 21-Point Array

With no experimental error, we could find the coefficients of 1, x^2+y^2, and x^4+y^4 by using the central point and the two points nearest it on the positive and negative coordinate axes. For the coefficient of x^2y^2 we should need also four points on 45° lines. Thus the smallest array sufficient for the purpose would be 0123. With experimental error present, we must have extra degrees of freedom with which to minimize the variance. For this purpose we add the points 6 on the axes and 5 on the 45° lines. Our array is therefore the 21-point array 012356.

Coefficients for the 21-Point Array

Instead of calculating orthogonal polynomials for array 012356, we apply the minimum-variance principle directly. The formula (3-1) must be exact, in the absence of experimental error, when η is 1, x^2+y^2, x^4+y^4, or x^2y^2. The minimization of the variance (3-2) is therefore subject to four conditions and requires four Lagrangian multipliers, which are determined by four simultaneous equations. The left members of these equations are independent of the quantity being estimated and are the same as in the normal equations of the least-squares form of the problem. The right members depend on the quantity being estimated. If this quantity is

$$\omega = C_0\eta(0, 0, 0) + C_1\eta_{zz}(0, 0, 0) + C_2\eta_{zzzz}(0, 0, 0), \tag{4-1}$$

then

$$a_p = L_1 + L_2(x_p^2 + y_p^2) + L_3(x_p^4 + y_p^4) + L_4x_p^2y_p^2, \tag{4-2}$$

where the L's are the Lagrangian multipliers, determined by

$$\left.\begin{aligned} 21\,L_1 + \quad 96\,L_2 + \quad 528\,L_3 + \quad 68\,L_4 &= \quad C_0, \\ 96\,L_1 + \quad 664\,L_2 + \quad 4216\,L_3 + \quad 520\,L_4 &= -\,4\,C_1, \\ 528\,L_1 + 4216\,L_2 + 31{,}384\,L_3 + 2056\,L_4 &= \quad 48\,C_2, \\ 68\,L_1 + \quad 520\,L_2 + \quad 2056\,L_3 + 1028\,L_4 &= \quad 8\,C_2. \end{aligned}\right\} \tag{4-3}$$

Table 6 lists best coefficients and resulting values of σ_w/σ for estimation of $\eta(0, 0, 0)$, $\eta_{zz}(0, 0, 0)$, and $\eta_{zzzz}(0, 0, 0)$.

Table 7 lists best coefficients and resulting values of σ_w/σ for estimation of $\eta^*(0, 0, 1)$ and $\eta^*(0, 0, 2)$.

Coefficients for Larger Arrays

For the 25-point array 0123569 and for the 49-point square array, the easiest way to compute the coefficients is to use the orthogonal polynomials and their derivatives. The necessary derivatives for array 0123569 can be found either by differencing of the numerical values or by differentiation of formulas (2-5) and (2-6).

Table 8 lists best coefficients and resulting values of σ_w/σ for estimation of $\eta_{zz}(0, 0, 0)$ and $\eta_{zzzz}(0, 0, 0)$, for the 25-point array 0123569. The table gives coefficients both for second- or third-degree estimation and for fourth- or fifth-degree estimation.

Table 9 lists best coefficients and resulting values of σ_w/σ for fourth- or fifth-degree estimation of $\eta(0, 0, 0)$, $\eta_{zz}(0, 0, 0)$, and $\eta_{zzzz}(0, 0, 0)$ for the 49-point square array. Coefficients for $\eta^*(0, 0, z)$ can be found, for any specified z, by linear superposition of the coefficients already given; σ_w^2/σ^2 can then be calculated by (3-2).

Comparison of Arrays

The variance of the estimate $\hat{\eta}_{zzzz}$ depends, as does that of $\hat{\eta}_{zz}$, both on the scale of the array and on its geometric form. To remove the scale factor, we may multiply σ_w/σ by the fourth power of a characteristic length. We multiply by $(\overline{r^2})^2$ and thus get a criterion $\mu = (\overline{r^2})^2\sigma_w/\sigma$ for estimation of $\hat{\eta}_{zzzz}$.

Table 10 compares the arrays considered in this section, for fourth-degree estimation of even vertical derivatives.

5. NEAR-BEST COEFFICIENTS

The Problem

The coefficients found in Section 4 guarantee the smallest possible variance in the estimated quantity, but they have many-digit numerators. On desk calculators and on the IBM 602A calculating punch, the multiplication time is proportional to the number of digits in the multiplier; the best one can do is to choose

as multiplier whichever of the two factors has fewer digits. On the IBM 604, the number of digits does not limit the speed of a multiplication, but it does limit the number of coefficients that can be stored for use in one pass of the cards. We may therefore prefer, in routine calculations, to replace the best coefficients by ones with fewer digits, even at some cost in precision.

Method of Solution

We modify the minimum-variance method as follows. We require, as before, that the estimation formula (3-1) be exact for polynomials of specified forms; but instead of making the variance (3-2) as small as it can be under these restrictions, we try to find simple coefficients that bring it acceptably close to this smallest value.

Illustration for Array 012356

We consider fourth-degree estimation of $\eta(0, 0, 0)$ for array 012356. We seek coefficients of the form $a_p = N_p/D$, where the N_p's and D are integers. The exactness conditions for $\eta = 1$, x^2+y^2, x^4+y^4, and x^2y^2 require

$$\left.\begin{aligned} N_0 + 4(N_1 + N_2 + N_3 + N_5 + N_6) &= D, \\ N_1 + 2N_2 + 4N_3 + 8N_5 + 9N_6 &= 0, \\ N_1 + 2N_2 + 16N_3 + 32N_5 + 81N_6 &= 0, \\ N_2 + 16N_5 &= 0. \end{aligned}\right\} \tag{5-1}$$

In Table 6, a_5 is very small. We therefore try a solution with $N_5 = 0$; the last equation (5-1) then requires $N_2 = 0$. With $N_2 = N_5 = 0$, the first equation makes D an integer if N_0, N_1, N_3, and N_6 are integers; elimination of N_1 from the second and third equations gives $N_3 = -6N_6$, so that N_3 will be an integer if N_6 is; and substitution of this value of N_3 in the second or third equation gives $N_1 = 15N_6$, so that N_1 will be an integer if N_6 is. Therefore we can satisfy both the exactness conditions and the integer requirements by assigning arbitrary integer values to N_0 and N_6: the resulting values of the other integers are

$$N_1 = 15N_6, \qquad N_3 = -6N_6, \qquad D = N_0 + 40N_6. \tag{5-2}$$

To find whether a solution with $N_2 = N_5 = 0$ can give a satisfactorily small variance, we compute the minimum variance attainable when the N's and D are subject to this condition and to (5-2) but are not restricted to integer values. This requires minimization with respect to $f = N_0/N_6$ of

$$\begin{aligned} \sigma_w^2/\sigma^2 &= [N_0^2 + 4(N_1^2 + N_3^2 + N_6^2)]/D^2 \\ &= (f^2 + 1048)/(f + 40)^2. \end{aligned} \tag{5-3}$$

The minimum occurs at $f = 131/5 = 26.2$ and gives $\sigma_w/\sigma = 0.6291$. The increase from the best value 0.6103 (Table 6) is not serious; therefore we accept the simplification $N_2 = N_5 = 0$.

We must now approximate 131/5 with the ratio of two small integers, which can then be used as N_0 and N_6. A systematic method exists for approximating a given quantity with successive rational fractions of increasing complexity (Chrystal, 1952, p. 444–452): expand the given quantity as a continued fraction; the successive convergents (principal and intermediate) of the continued fraction are the desired approximations. The continued-fraction expansion of 131/5 is $26+1/5$; the principal convergents are the approximation 26 and the exact value. The former gives $N_0=26$, $N_6=1$; by (5-3), $\sigma_w/\sigma=0.6291$. This is identical to four figures with the smallest σ_w/σ compatible with $N_5=0$. Equations (5-2) now give $N_1=15$, $N_3=-6$, $D=66$.

Table 11 lists these near-best coefficients for $\bar{\eta}(0, 0, 0)$. They involve only 1- and 2-digit numerators and are almost as precise as the best coefficients.

Other Results for Array 012356

Near-best coefficients for $\bar{\eta}_{zz}(0, 0, 0)$ can be found by the same method. N_5 can again be set equal to zero; then $N_2=0$, and N_0, N_1, and D will be integers if N_3 and N_6 are. The smallest σ_w/σ attainable with $N_2=N_5=0$ is 1.452, for $N_3/N_6=-2207/423$. The first four principal convergents of the continued-fraction expansion of 2207/423 are 5/1, 21/4, 26/5, and 47/9; they give $\sigma_w/\sigma=1.878$, 1.471, 1.457, and 1.452 respectively. The last three are satisfactory. There are no intermediate convergents between 5/1 and 26/5 or between 21/4 and 47/9.

Table 11 lists the three sets of near-best coefficients for $\bar{\eta}_{zz}(0, 0, 0)$.

For $\bar{\eta}_{zzzz}(0, 0, 0)$ a nonvanishing N_5 is necessary; N_0, N_1, N_2, and D will be integers if N_3, N_5, and N_6 are. The optimum ratios $-N_3/N_5=111{,}675/17{,}294$ and $N_6/N_5=34{,}015/17{,}294$ (Table 6) must be approximated simultaneously. This can be done by finding the successive approximations to each, by the continued-fraction method, and combining them in various ways. For $-N_3/N_5$ the first two principal convergents are 6/1 and 13/2; for N_6/N_5 the first three are 1/1, 2/1, and 59/30. By combining these we get for $(-N_3, N_5, N_6)$ the sets of values (6, 1, 1), (6, 1, 2), (13, 2, 4), and (195, 30, 59); these give $\sigma_w/\sigma=45.20$, 3.010, 2.344, and 2.327. The third is satisfactorily close to the minimum, 2.322. The coefficients corresponding to the second set, though not highly precise, have the advantage of one-digit multipliers. A still better set of one-digit multipliers can be obtained by combining the principal convergent 2/1 for N_6/N_5 with the intermediate convergent 7/1 for $-N_3/N_5$ (this lies between the principal convergents of even order 1/0 and 13/2): $(-N_3, N_5, N_6)=(7, 1, 2)$, $\sigma_w/\sigma=2.770$.

Table 11 lists these near-best coefficients for $\eta_{zzzz}(0, 0, 0)$.

Table 11 also lists near-best coefficients for $\bar{\eta}^*(0, 0, 1)$ and $\eta^*(0, 0, 2)$; they were found by similar methods.

Larger Arrays

With more complex arrays, it is necessary to approximate a number of

quantities simultaneously with ratios of small integers. A method of doing so has been developed by Rosser (1950). His method is a generalization of the continued-fraction method.

Tables 12–13 list near-best coefficients, computed mostly by this method, for the 25- and 49-point arrays.

Smaller Arrays

The best second-degree coefficients of Tables 3–5 are already simple, but in some cases they can be replaced by even simpler near-best coefficients without serious loss of precision; this saves time in routine work with desk calculators. Table 14 lists a few such near-best coefficients. Satisfactory numerators for the noncentral points can usually be found by inspection, or by rounding the original numerators; the numerator for the central point and the denominator are then determined by the exactness conditions. This simple method was also used to derive the second-degree coefficients in Table 12.

Remarks

Regardless of how the coefficients are found, they are acceptable if (1) they satisfy the exactness conditions and (2) they give a variance satisfactorily close to the smallest attainable variance. The tables show that sometimes the near-best coefficients give the same variance, to four figures, as the best. Therefore "best" coefficients, in any practical sense of the word, are not unique.

Two sets of coefficients that give practically the same variance will not necessarily give indistinguishable results; but when the two results differ, either is as good a bet as the other.

When the error distribution is normal, the estimate calculated with best coefficients is an *efficient* estimate, in the statistical sense; and the ratio of the variance of this estimate to the variance of any other is the *efficiency* of the other. For instance, the near-best coefficients in Table 13 give $\sigma_w/\sigma = 0.5373$ whereas the corresponding best coefficients (Table 9) give 0.5303; the efficiency of the near-best estimate is $(0.5303/0.5373)^2 = 0.97 = 97\%$.

6. NUMERICAL EXAMPLE

Outline of Procedure

Table 6-1[2] gives g_i at points (x_i, y_i) of a 13×13 square grid. The object is to estimate the second vertical derivative at the 49 points of the central 7×7 square (Figure 2).

The polynomial degree will be determined by two methods: (1) one-dimensional orthogonal-polynomial analysis of the 7-point sets of points A, B, C, D of Figure 2; (2) two-dimensional symmetrized-orthogonal-polynomial analysis of the central 7×7 square. The variance of the data will be estimated.

[2] See note 1.

TABLE 6-1

DATA FOR ILLUSTRATIVE PROBLEM
VERTICAL INTENSITY IN MILLIGALS ABOVE 480
Unit of x and y (one grid spacing) is $\cong$1 mile

x = / y	−6	−5	−4	−3	−2	−1	0	+1	+2	+3	+4	+5	+6
+6	8.23	9.73	10.61	11.40	12.29	13.17	14.17	15.12	16.12	17.16	18.39	19.48	20.69
+5	9.21	10.07	10.84	11.67	12.55	13.43	14.37	15.22	16.31	17.35	18.62	19.85	20.90
+4	9.57	10.38	11.17	11.92	12.80	13.67	14.49	15.41	16.38	17.51	18.79	20.04	21.38
+3	9.89	10.75	11.52	12.24	13.00	13.79	14.65	15.63	16.58	17.78	19.10	20.37	21.75
+2	10.34	11.05	11.72	12.45	13.21	14.07	14.86	15.98	17.03	18.22	19.39	20.85	22.21
+1	10.72	11.37	12.07	12.80	13.47	14.43	15.35	16.34	17.43	18.67	20.02	21.25	22.64
0	11.18	11.85	12.50	13.16	13.94	14.83	15.75	16.88	18.07	19.31	20.63	21.89	23.24
−1	11.71	12.36	12.93	13.64	14.55	15.34	16.44	17.50	18.81	19.92	21.31	22.57	23.82
−2	12.29	12.81	13.51	14.31	15.21	16.10	17.13	18.27	19.49	20.76	21.86	23.21	24.44
−3	12.86	13.61	14.31	15.01	15.90	16.91	17.99	19.07	20.24	21.53	22.67	23.96	24.99
−4	13.46	14.32	15.05	15.89	16.86	17.78	18.82	19.93	21.00	22.27	23.41	24.53	25.73
−5	14.27	14.97	15.86	16.71	17.55	18.61	19.63	20.73	21.82	22.94	24.12	25.21	26.36
−6	14.82	15.65	16.57	17.49	18.40	19.32	20.47	21.53	22.59	23.73	24.77	25.90	27.05

If degree 2 or 3 is sufficient, η_{zz} at each point will be estimated by use of the array 016 centered at that point. The coefficients used will be the "best" coefficients given in Table 3. The variance of η_{zz} will be estimated.

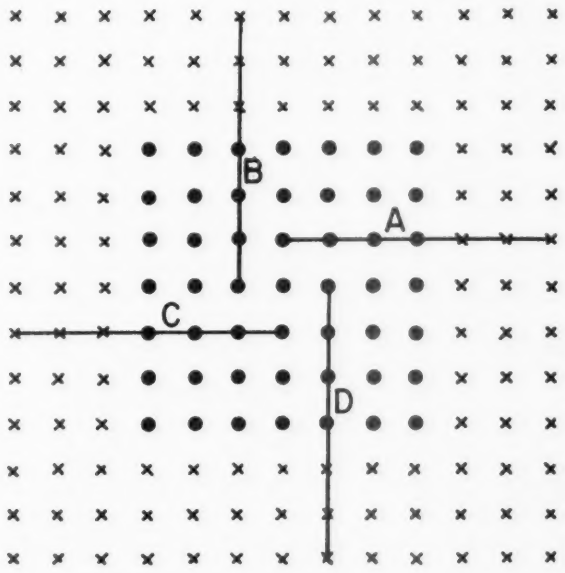


FIG. 2. Geometry of the illustrative problem.
● Points of the central 7×7 square, used: (1) for two-dimensional symmetrized-orthogonal-polynomial analysis; (2) as points at which η_{zz} is to be estimated.
× Auxiliary points needed for estimation of η_{zz} at the points ●.
——— Linear arrays A, B, C, and D used for one-dimensional orthogonal-polynomial analysis.

If degree 4 or 5 is required, η_{zz} at each point will be estimated by use of the 7×7 square array centered at that point. The coefficients used will be the "near-best" coefficients given in Table 13. The variance of η_{zz} will be estimated.

The procedure so far described is not dependent on normality of the error distribution. On the further assumption that the distribution is normal, 95% confidence limits will be calculated for the variance σ^2 of the data and for the estimates $\bar{\eta}_{zz}$.

Choice of Degree and Estimation of Variance

Linear Arrays.—Table 6-2 gives the results of the orthogonal-polynomial

TABLE 6-2

ORTHOGONAL-POLYNOMIAL ANALYSIS OF LINEAR ARRAYS

Array	r	$S_r c_r^2$	s_r^2	$n-r-1$
A	0	2477.84143	7.013828	6
	1	41.96866	0.022286	5
	2	0.10150	0.003203	4
	3	0.00735	0.001820	3
	4	0.00062	0.002420	2
	5	0.00428	0.000560	1
	6	0.00070	—	0
B	0	1354.97315	0.332058	6
	1	1.94515	0.000440	5
	2	0.03125	0.003988	4
	3	0.01127	0.001560	3
	4	0.00190	0.001300	2
	5	0.00138	0.001400	1
	6	0.00140	—	0
C	0	1343.31155	2.851392	6
	1	16.92618	0.030434	5
	2	0.16740	0.003093	4
	3	0.00282	0.003983	3
	4	0.00011	0.005020	2
	5	0.00986	0.001980	1
	6	0.00197	—	0
D	0	2561.69830	2.903767	6
	1	17.39579	0.005362	5
	2	0.01630	0.002628	4
	3	0.00960	0.000303	3
	4	0.00037	0.000270	2
	5	0.00001	0.000530	1
	6	0.00043	—	0

analysis of the four sets of data A, B, C, and D. By inspection of the $S_r c_r^2$ and s_r^2 columns, we see that terms $r>3$ may be dropped in A, B, and D and that terms $r>2$ may be dropped in C. In each case the conclusion is that for estimation of η_{zz}, the second- and third-degree formulas should be used.

The four estimates of variance are $10^6 s^2 = 1820$, 1560, 3693, and 303; they are based respectively on 3, 3, 4, and 3 degrees of freedom (d.f.). The pooled estimate is $s^2 = 0.001986$, $s = 0.04456$, based on 13 d.f.

Square Array.—Table 6-3 gives the results of the symmetrized-orthogonal-

polynomial analysis of the central 7×7 square; it was carried out by use of Table 1. By inspection of the $S_{rs}c_{rs}^2$ and s_{rs}^2 columns, we see that of the functions even in x and y and symmetric between x and y, only u_{00} and u_{02} need to be kept; terms of degree 4 or greater may be dropped. The conclusion is that for estimation of η_{zz}, the second- and third-degree formula should be used. This confirms the conclusion from linear arrays.

The estimate of variance is $s^2=0.00300$; it is based on 8 d.f. This estimate is not independent of the estimate based on linear arrays, for some points of the linear arrays used are also points of the central 7×7 square. The two estimates

TABLE 6-3

ORTHOGONAL-POLYNOMIAL ANALYSIS OF CENTRAL 7×7 SQUARE

r	s	Degree $r+s$	$S_{rs}c_{rs}^2$	s_{rs}^2	No. of d.f.
0	0	0	12867.33718	0.28506	9
0	2	2	2.54150	0.00300	8
0	4	4	0.00502	0.00271	7
2	2		0.00944	0.00160	6
0	6	6	0.00012	0.00189	5
2	4		0.00120	0.00206	4
2	6	8	0.00083	0.00247	3
4	4		0.00181	0.00281	2
4	6	10	0.00002	0.00559	1
6	6	12	0.00559	—	0

must therefore not be combined. Of the two, the more precise is that based on the linear arrays, because it is the average of the squares of 13 random variables rather than of only 8.

Confidence Limits for the Variance.—From the estimate $s^2=0.001986$ based on 13 d.f., we can find 95% confidence limits for the variance σ^2 of g. The method was explained and illustrated in Part 1; it requires use of tables of the chi-square distribution, and it is valid only if the error distribution is normal. The confidence interval thus calculated is

$$0.001044 < \sigma^2 < 0.005154 \qquad (95\%). \tag{6-1}$$

From the estimate $s^2=0.00300$ based on 8 d.f., $0.00137<\sigma^2<0.01101$ (95%). This confidence interval is over twice as wide as the other. However, if data had been available for one more value of x and for one more value of y, four independent 7×7 squares could have been analyzed and the four estimates of variance pooled; this would have given a more precise estimate.

Estimation of Second Vertical Derivative

Calculation of Estimates.—In accordance with the results just presented, we estimate η_{zz} by use of best second-degree coefficients for array 016 (Table 3). This array permits estimation of η_{zz} at any point that has three or more neighbors along each positive and negative coordinate axis: namely, at any point of the central 7×7 square.

Table 6-4, column 3, gives the estimates thus calculated.

The estimated standard deviation of any individual $\hat{\eta}_{zz}$ is

$$s_w = (\sigma_w/\sigma)s = 0.326 \times 0.04456 = 0.01453.$$

Confidence Limits for η_{zz}.—If normality is assumed, the 95% confidence limits for any individual η_{zz} are $_{zz} \pm t_{5\%}s_w = \hat{\eta}_{zz} \pm 2.160 \times 0.01453 = \eta_{zz} \pm 0.0314$; here $t_{5\%} = 2.160$ is the value of Student's $|t|$, in 13 d.f., that is exceeded with probability 5%.

For the central point of the whole array of data points, $_{zz} = -0.2101$, and we may state with 95% confidence that

$$-0.2415 < \eta_{zz} < -0.1787 \qquad (95\%). \tag{6-2}$$

Joint confidence statements about values of η_{zz} at several adjacent points would require a more intricate statistical theory.

Contours.—Figure 3 is a contour map of the original g values in the central

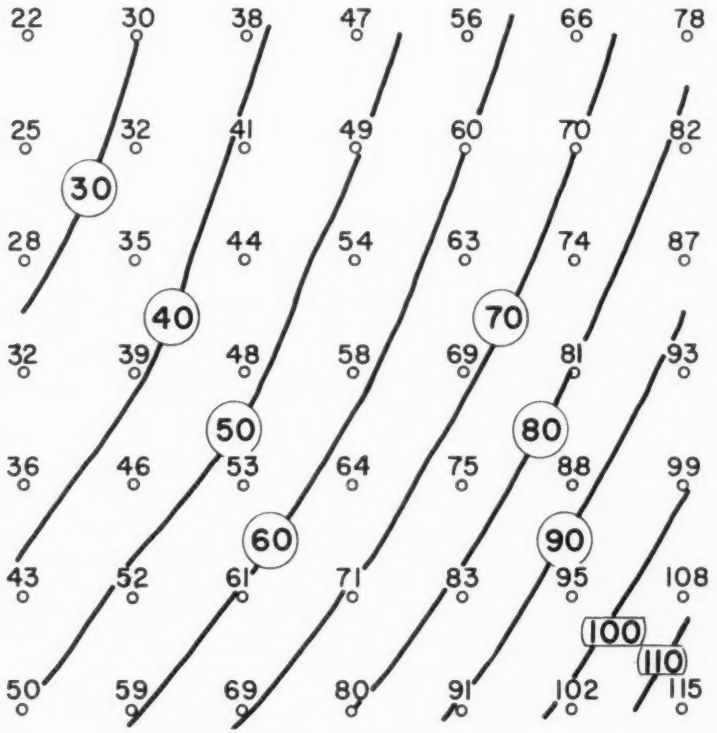
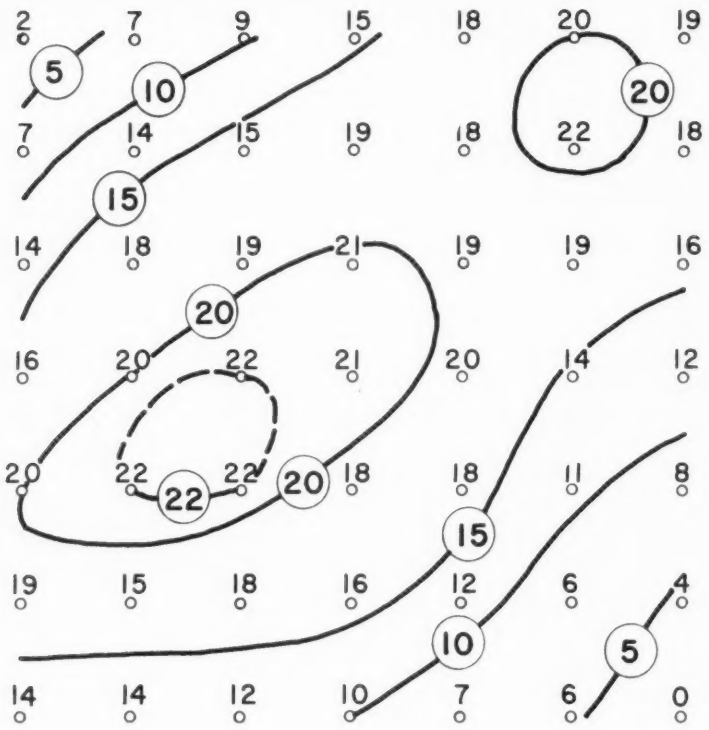


Fig. 3. Contours of observed intensity g over the central 7×7 square of Figure 2. The numbers at the grid points and on the contours are values of $10(g - 490)$ (g in milligals).

TABLE 6-4

ESTIMATES AND TRUE VALUES OF SECOND VERTICAL DERIVATIVE

x	y	$-\hat{\eta}_{zz}$ 016 2d degree	$-\hat{\eta}_{zz}$ 7×7 square 4th degree	$-\eta_{zz}$
−3	+3	.0234	.0551	.0292
	+2	.0705	.1114	.0703
	+1	.1380	.1626	.1389
	0	.1648	.1956	.2205
	−1	.1983	.2412	.2590
	−2	.1931	.2191	.2146
	−3	.1432	.1551	.1285
−2	+3	.0703	.0647	.0516
	+2	.1427	.1356	.1012
	+1	.1773	.1895	.1805
	0	.2039	.1958	.2756
	−1	.2163	.2166	.3190
	−2	.1510	.2250	.2602
	−3	.1365	.1408	.1529
−1	+3	.0929	.0878	.0878
	+2	.1495	.1483	.1374
	+1	.1880	.2024	.1974
	0	.2237	.2280	.2602
	−1	.2191	.2251	.2809
	−2	.1815	.1984	.2247
	−3	.1167	.1272	.1325
0	+3	.1470	.1537	.1490
	+2	.1915	.2036	.1985
	+1	.2068	.2236	.2187
	0	.2101	.2284	.2187
	−1	.1832	.2105	.1985
	−2	.1599	.1702	.1490
	−3	.0998	.0997	.0873
+1	+3	.1825	.1982	.2247
	+2	.1753	.2034	.2809
	+1	.1939	.2105	.2602
	0	.1904	.2082	.1974
	−1	.1780	.1802	.1374
	−2	.1185	.1555	.0878
	−3	.0712	.0714	.0472
+2	+3	.2004	.2701	.2602
	+2	.2246	.2319	.3190
	+1	.1862	.1988	.2756
	0	.1301	.1454	.1805
	−1	.1088	.1104	.1012
	−2	.0618	.0884	.0516
	−3	.0572	.0436	.0219
+3	+3	.1857	.2262	.2146
	+2	.1780	.2206	.2590
	+1	.1641	.1822	.2205
	0	.1240	.1360	.1389
	−1	.0830	.0693	.0703
	−2	.0390	.0379	.0292
	−3	.0044	.0079	.0075



(a)

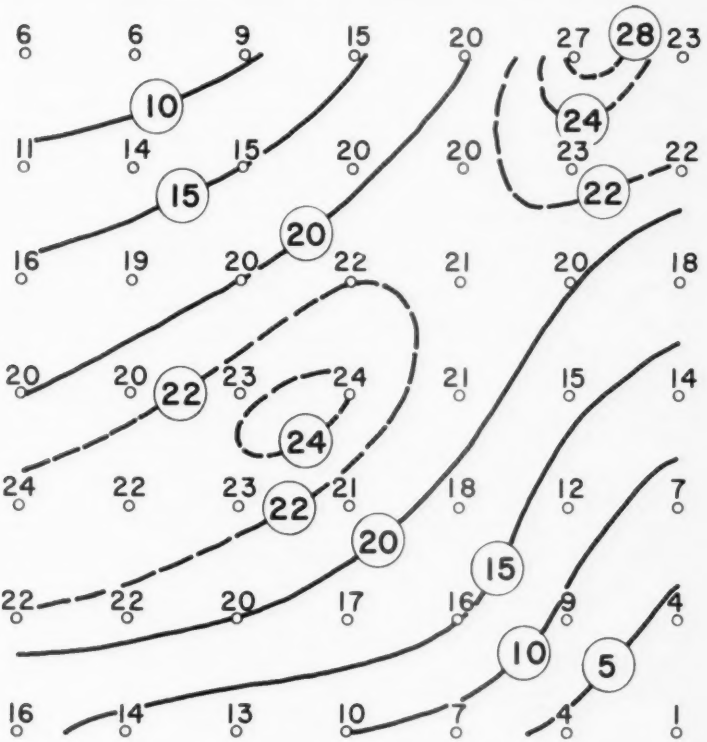
FIG. 4 (a). Legend on page 130.

7×7 square; Figure 4(a) is a contour map of the estimated second vertical derivative. The latter contours give a much clearer picture of the anomaly. If other knowledge suggests salt domes as the cause of anomalies in this region, the second-derivative map strongly suggests that there are two salt domes, and that their centers are approximately at $(-1.5, -0.5)$ and at $(+2.0, +2.5)$.

Confidence limits for the coordinates of a maximum or minimum of η_{zz} would be useful. So would a significance test for a maximum or minimum. To decide between one salt dome and two, we need a significance test for the saddle point between the two apparent minima. The theory summarized and applied in this article does not include the solution of these statistical problems.

Examination of Conclusions

Nature of the Example.—The data of Table 6-1 were calculated by superposing: (1) the vertical field intensity of a semi-infinite vertical line source with



(b)

FIG. 4 (b). Legend on page 130.

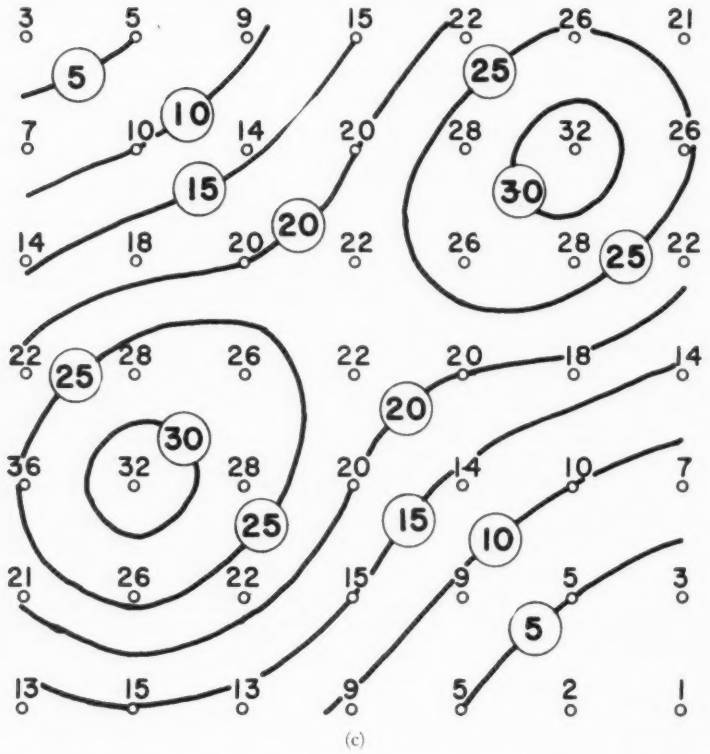
top at depth 4 below $(-2, -1)$; (2) the vertical field intensity of a semi-infinite vertical line source with top at depth 4 below $(+2, +2)$; (3) a "regional anomaly" varying linearly in the direction $(+2/\sqrt{5}, -1/\sqrt{5})$; (4) independent normal random errors of standard deviation 0.045. The formula used is

$$g_i = 500 + x_i - (1/2)y_i - 10/r_{1i} - 10/r_{2i} + \epsilon_i, \tag{6-3}$$

where

$$\left.\begin{aligned} r_{1i}^2 &= 16 + (x_i + 2)^2 + (y_i + 1)^2, \\ r_{2i}^2 &= 16 + (x_i - 2)^2 + (y_i - 2)^2. \end{aligned}\right\} \tag{6-4}$$

The errors ϵ_i were calculated by reading random normal deviates from Wold's (1948) table and multiplying them by 0.045. The random normal deviates were taken from the top left 13×13 square on pages 4-5 of the table: they were kept in the same two-dimensional order in Table 6-1.



(c)

FIG. 4 (c). Contours of $-100\,\eta_{zz}$ over the central 7×7 square of Figure 2: (a) estimates from the array 016 about each estimation point, with best second-degree coefficients; (b) estimates from the 7×7 square array about each estimation point, with near-best fourth-degree coefficients; (c) true values.

Variance Estimates.—The known variance is $(0.045)^2=0.002025$. It falls within the confidence interval (6-1) and also within the wider confidence interval based on 8 d.f.

Estimates of Second Vertical Derivative.—The true second vertical derivative η_{zz} can be calculated by differentiating (6-3) with i and ϵ_i omitted. At the central point, $\eta_{zz}=-0.21865$. This falls within the confidence interval (6-2). Values at other points are given in Table 6-4, column 5.

At points near the sources, the known values of η_{zz} do not fall within the 95% confidence interval; there is a systematic bias. For instance, at $(-2, -1)$, directly over one of the sources, $\eta_{zz}=-0.3190$; this deviates from the estimate $\widehat{\eta}_{zz}=-0.2163$ by -0.1027, whereas the confidence interval is ±0.0314. The

general effect of the bias can be seen by comparing the estimated contours, Figure 4(a), with the true contours, Figure 4(c). The peaks are blunted, because the high-order terms needed to follow them are submerged in error and cannot be evaluated.

It helps little to keep fourth-degree terms, in disregard of the orthogonal-polynomial analysis. Figure 4(b) shows contours calculated with near-best fourth-degree coefficients for the 7×7 square (Table 13); the numerical values are listed in Table 6-4, column 4. The bias is somewhat decreased, but the random errors are increased ($\sigma_w/\sigma=0.537$ against 0.326), so that the contours are less precisely located.

The basic difficulty is this: where the true intensity is changing rapidly with position, high-order terms are important in the derivatives but are not significant in the original set of observed intensities. No treatment of the original data can produce reliable estimates of these terms; for this purpose it is necessary to get supplementary data of greater precision. The greater precision can usually not be attained by improving the precision of individual measurements; it must be attained by putting the measurement points closer together. The points must sometimes be put closer together for another reason too: that in a region of rapid change, the terms needed include ones of such high order that they cannot be evaluated with the original number of points, even in the absence of experimental error (cf. Part 1, Section 6, Example 3). The number of points must then be increased. This may be done by spacing them closer together or by extending the range; but when the polynomial is only an approximation to the function being fitted, the two methods are not equivalent. The former method is suitable when, as here, the object is to fit the function better over the specified range; the latter method is suitable when the object is to fit the function over a wider range.

Under these conditions, statistical analysis of the original data cannot provide reliable estimates of derivatives in the regions of rapid change. It may nevertheless provide estimates that suffice for localizing such regions. If reliable information is important, supplementary measurements can then be taken over a limited area. Without such supplementary measurements, we can only resort to analogy with known cases—either previous surveys in which denser data were taken, or theoretical models.

The following analogy may be useful to readers familiar with the theory of electric circuits and filters. The calculation methods described are analogous to a differentiation circuit preceded (or followed) by a low-pass filter; the cutoff frequency is so chosen that above it, the received message contains more noise than signal. If the signal contains no important components above the cutoff frequency, the result is a reliable reconstruction of the differentiated signal; if it contains such components, the result is distorted. Raising the cutoff frequency does not give a better result; it gives only a noisier one. To get a better result, we must increase the signal-to-noise ratio in the message we are operating on. In

the gravity calculation, η is analogous to the unperturbed signal, g to the received message; the errors ϵ are analogous to the noise. The components c_0u_0, c_1u_1, etc. of g are analogous to the Fourier components of the received message; the index r is analogous to the frequency; and k is analogous to the cutoff frequency.

Estimates of Location.—Despite the bias, the second-degree contours give a fair idea of the horizontal location of the sources: the source actually at $(-2,-1)$ appears to be near $(-1.5, -0.5)$; the source actually at $(+2, +2)$ appears to be near $(+2.0, +2.5)$. The fourth-degree contours locate the sources less precisely. Either set of contours is satisfactory for determining the region in which supplementary measurements are desirable.

The problem of estimating *vertical* location is outside the scope of this article.

Conclusion

This example shows that all the principles illustrated in Part 1 still apply in two dimensions; only the practical working formulas and procedures are different.

7. GENERAL ARRAYS; CORRELATED DATA

The Problem

All the preceding theory supposes that the values g_i at the grid points are statistically independent, or at least uncorrelated (mean of $\epsilon_i\epsilon_j=0$ for $j\neq i$). This would be true if the grid points were the original stations where independent measurements were taken. In practice, however, the stations are distributed irregularly; values on a regular grid, if they are to be used, must be obtained from the station values by interpolation on contour maps or by some more elaborate method. Values so obtained will be correlated.

To handle this problem rigorously requires laborious calculations, possible only with high-speed electronic calculators. There are two possibilities: (1) to base all calculations directly on the station values; (2) to calculate grid values and then to base further calculations on them.

Direct Use of Station Values

To estimate, say, η_{zz} at a given point, it is necessary to use N station values G_k near that point, with N large enough to permit evaluation of all significant terms with satisfactory precision. The principles and the possible procedures are the same as for regularly spaced points; but every estimation point has its own peculiar array of data points, its own peculiar normal-equation matrix, and its own peculiar set of orthogonal polynomials. If η_{zz} and other quantities are to be estimated at 1,000 points, not 1 but 1,000 sets of orthogonal polynomials must be calculated, or equivalent results must be obtained by conventional least-squares methods.

Advantages of orthogonalization have already been mentioned; the following advantage is particularly important when the points are irregularly distributed. Suppose we arrange the functions (1-1) in a plausible order and then try to fit by least squares, without orthogonalization, to the first K functions. With irregularly distributed points, it will often happen that some pairs of these functions are so close to being linearly dependent that the least-squares matrix is nearly singular. This situation can be very troublesome. But if we first orthogonalize the functions by the method of Part 1, equations (5-10), then linear near-dependence will show up in the orthogonalization process: for any U that is nearly dependent on an earlier one can be almost completely expressed as a linear combination of u's already evaluated. Then this U can be rejected and the next one tried instead. Automatic testing and rejection can be incorporated into the machine program.

Calculation of Grid Values

To calculate grid values from the station values, it is necessary to use N station values G_k near each grid point, and to estimate η at the specified grid point by the method just outlined. It is also necessary to calculate the variances and covariances of the estimates, per unit variance of the data. If the estimated intensities g_i, g_j at grid points i, j are calculated from the station values G_k by formulas

$$g_i = \sum_k A_{ik} G_k, \qquad g_j = \sum_k A_{jk} G_k, \tag{7-1}$$

then the variances and covariances are

$$\sigma_{ij}^2 = E[(g_i - \eta_i)(g_j - \eta_j)] = \sigma^2 \sum_k A_{ik} A_{jk} \equiv \sigma^2 k_{ij}, \tag{7-2}$$

where E denotes expected value. The covariance receives a contribution from each station that is used both in the calculation of g_i and in the calculation of g_j.

Calculations Based on Correlated Grid Values

In further calculations, the g_i's play the same role as in the earlier sections of this article; but the method of finding best linear estimates of other quantities is now more complicated. When the variances and covariances are of the form (7-2), with known k_{ij}'s, the theory of best linear estimates requires the following generalization (Aitken, 1935): instead of minimizing the sum of squares of the deviations $\hat{\eta}_i - g_i$, we must minimize

$$Q = \sum_i \sum_j p_{ij} (\hat{\eta}_i - g_i)(\hat{\eta}_j - g_j), \tag{7-3}$$

where (p_{ij}) is the matrix inverse to (k_{ij}).

If we move from one estimation point to another, always using a definite array such as 0136 about the estimation point, the factors k_{ij} will vary. It is therefore no longer possible to compute sets of coefficients that can be used consistently for all estimation points. Furthermore the definition of orthogonality is now $\Sigma_i\Sigma_j p_{ij}u_{ri}u_{rj}=0$ for $s\neq r$, and therefore the orthogonal polynomials vary with the estimation point.

In view of these complications, there seems to be little point in using grid values at all.

Neglect of Correlation

The case for grid values will become stronger if we can justify the approximation $k_{ij}=0$ for $j\neq i$ (no correlation) and $k_{11}=k_{22}=\cdots=k$ (equal variances); briefly, $k_{ij}=k\delta_{ij}$. In preceding sections this approximation has been made; and when grid values are read from contour maps, any greater refinement is of dubious value. But when least-squares methods are applied directly to the station values, neglect of correlations can be justified only by demonstrating that they are negligible.

An estimate based on the approximation $k_{ij}=k\delta_{ij}$ is still unbiased, but it has a larger variance than the best linear estimate. The way to test the approximation is to compare the variance of the resulting estimates with the minimum variance attainable. An estimate $w=\Sigma_i a_i g_i$, regardless of how the a_i's were derived, has variance

$$\sigma_w^2 = \sigma^2 \sum_i \sum_j k_{ij}a_i a_j. \tag{7-4}$$

Calculations of this sort, on a large sample of representative gravity data, can determine whether the simplification $k_{ij}=k\delta_{ij}$ is acceptable under representative conditi[illegible]

8. ACKNOWLEDGMENTS

Mr. F. L. Johnson, of this laboratory, introduced me to the gravity problem, provided constant encouragement, and made many helpful suggestions. The late Dr. John M. Pearson followed the work with sympathetic interest; he made stimulating comments on a number of the problems encountered.

Mr. B. E. Richert, of the Sun Oil Company's Geophysical Laboratory, worked with me in early stages of the work in 1947. During the next year, he and I independently developed different sets of coefficients for simultaneous graduation and differentiation. It was this work of Mr. Richert's that led me to seek a criterion for choosing "best" coefficients.

Mr. Carl W. Dempsey has worked with me since 1948. I am indebted to him for most of the calculation of orthogonal polynomials (DeLury's tables were not then available) and of their derivatives; for extensive numerical trials of various

methods of analysis; and for the development of IBM machine procedures and the systematic application of them to large bodies of data.

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TABLE 1

SYMMETRIC ORTHOGONAL POLYNOMIALS FOR 49-POINT SQUARE ARRAY:
$u_{rr}(x, y) = \xi_r'(x)\xi_r'(y)$; $u_{rs}(x, y) = \xi_r'(x)\xi_s'(y) + \xi_s'(x)\xi_r'(y)$, $s \neq r$

Degree, $r+s$			0	2	4		6		8		10	12
Group Number (p)	$\lvert x\rvert$	$\lvert y\rvert$	u_{00}	u_{02}	u_{04}	u_{22}	u_{06}	u_{24}	u_{26}	u_{44}	u_{46}	u_{66}
0	0	0	1	− 8	+12	+16	−40	−48	+160	+36	−240	+400
1	1	0	1	− 7	+ 7	+12	− 5	−22	0	+ 6	+ 70	−300
2	1	1	1	− 6	+ 2	+ 9	+30	− 6	− 90	+ 1	+ 30	+225
3	2	0	1	− 4	− 1	0	−26	+28	+ 24	−42	+104	+120
4	2	1	1	− 3	− 6	0	+ 9	+21	+ 18	− 7	−111	− 90
5	2	2	1	0	−14	0	−12	0	0	+49	+ 84	+ 36
6	3	0	1	+ 1	+ 9	− 20	−19	+18	−104	+18	− 54	− 20
7	3	1	1	+ 2	+ 4	− 15	+16	− 4	+ 72	+ 3	+ 46	+ 15
8	3	2	1	+ 5	− 4	0	− 5	−35	− 30	−21	− 25	− 6
9	3	3	1	+10	+ 6	+25	+ 2	+30	+ 10	+ 9	+ 6	+ 1

r	s	$S_{rs} = \Sigma u_{rs}^2$
0	0	49
0	2	1176
0	4	2156
2	2	7056
0	6	12936
2	4	25872
2	6	155232
4	4	23716
4	6	284592
6	6	853776

TABLE 2

SYMMETRIC ORTHOGONAL POLYNOMIALS FOR 25-POINT ARRAY 0123569

Degree			0	2	4	
Group Number (p)	$\lvert x\rvert$	$\lvert y\rvert$	u_0	u_1	u_2	u_3
0	0	0	1	−168	+3780	+ 51352
1	1	0	1	−143	+1919	+ 36570
2	1	1	1	−118	+ 58	+ 25815
3	2	0	1	− 68	−1067	− 12288
5	2	2	1	+ 32	−5914	− 11496
6	3	0	1	+ 57	+2613	−108758
9	3	3	1	+282	+1446	+ 57319

r	$S_r = \Sigma u_r^2$
0	25
1	5 19400
2	2091 62380
3	7 22398 37544

TABLE 3

BEST SECOND-DEGREE COEFFICIENTS FOR ESTIMATING SECOND VERTICAL DERIVATIVE AT CENTER OF ARRAY, $\eta_{zz}(0, 0, 0)$

Array	n	σ_w/σ	μ	μ'	D'	p	$D'a_p$
016	9	0.326	1.45	2.94	338	0	+40
						1	+31
						6	−41
015	9	0.371	1.49	2.97	29	0	+ 4
						1	+ 3
						5	− 4
0124	17	0.512	1.57	2.56	259	0	+52
						1	+35
						2	+18
						4	−33
0123	13	0.822	1.77	3.29	77	0	+28
						1	+15
						2	+ 2
						3	−24
013	9	0.824	1.83	3.30	53	0	+20
						1	+11
						3	−16
025	9	0.412	1.83	3.30	106	0	+20
						2	+11
						5	−16
13	8	0.943	2.36	3.77	3	1	+ 1
						3	− 1
012	9	2.000	2.67	4.00	3	0	+ 4
						1	+ 1
						2	− 2
023	9	1.000	2.67	4.00	6	0	+ 4
						2	+ 1
						3	− 2
035	9	0.500	2.67	4.00	12	0	+ 4
						3	+ 1
						5	− 2
04	9	0.849	3.77	4.24	10	0	+ 8
						4	− 1

TABLE 4

BEST SECOND-DEGREE COEFFICIENTS FOR ESTIMATING INTENSITY AT CENTER OF ARRAY, $\eta(0, 0, 0)$

Array	n	σ_w/σ	D'	p	$D'a_p$
016	9	0.493	169	0	+41
				1	+36
				6	− 4
013	9	0.566	53	0	+17
				1	+12
				3	− 3
13	8	0.687	12	1	+ 4
				3	− 1

TABLE 5

BEST SECOND-DEGREE COEFFICIENTS FOR ESTIMATING MEAN OF UPWARD- AND DOWNWARD-CONTINUED INTENSITIES AT DEPTH 1 AT CENTER OF ARRAY, $\eta^*(0, 0, 1)$

Array	n	σ_w/σ	D'	p	$D'a_p$
016	9	0.623	676	0	+204
				1	+175
				6	− 57
013	9	0.932	106	0	+ 54
				1	+ 35
				3	− 22
13	8	1.118	4	1	+ 2
				3	− 1

TABLE 6

BEST FOURTH-DEGREE COEFFICIENTS FOR ESTIMATING VERTICAL INTENSITY AND ITS EVEN VERTICAL DERIVATIVES AT CENTER OF 21-POINT ARRAY 012356

$\omega=$	$\eta(0, 0, 0)$	$\eta_{zz}(0, 0, 0)$	$\eta_{zzzz}(0, 0, 0)$
p	$D'a_p$	$D'a_p$	$D'a_p$
0	+47,303	+1,164,660	+141,820
1	+25,185	+ 446,893	+ 47,609
2	+ 7,920	− 97,888	− 22,698
3	−15,420	− 798,409	−111,675
5	− 495	+ 6,118	+ 17,294
6	+ 2,735	+ 152,211	+ 34,015
$D'=$	127,003	12×127,003	127,003
$\sigma_w/\sigma=$	0.6103	1.443	2.322

TABLE 7

BEST FOURTH-DEGREE COEFFICIENTS FOR ESTIMATING MEAN OF UPWARD- AND DOWNWARD-CONTINUED INTENSITIES AT CENTER OF 21-POINT ARRAY 012356

$\omega=$	$\eta^*(0, 0, 1)$	$\eta^*(0, 0, 2)$
p	$D'a_p$	$D'a_p$
0	+1,220,876	+2,015,758
1	+ 549,471	+ 788,439
2	+ 34,747	− 141,160
3	− 640,127	−1,337,719
5	+ 5,766	+ 72,324
6	+ 125,933	+ 364,681
$D'=$	12×127,003	6×127,003
$\sigma_w/\sigma=$	1.377	4.942

TABLE 8

BEST SECOND- AND FOURTH-DEGREE COEFFICIENTS FOR ESTIMATING EVEN VERTICAL DERIVATIVES AT CENTER OF 25-POINT ARRAY 0123569

	Second Degree	Fourth Degree	
$\omega=$	$\eta_{zz}(0, 0, 0)$	$\eta_{zz}(0, 0, 0)$	$\eta_{zzzz}(0, 0, 0)$
p	$D'a_p$	$D'a_p$	$D'a_p$
0	+168	+477,260	+316,820
1	+143	+283,907	+164,139
2	+118	+ 97,414	+ 12,723
3	+ 68	− 83,501	− 88,737
5	− 32	−534,502	−474,054
6	− 57	+ 12,989	+173,693
9	−282	+104,378	+133,031
$D'=$	5194	2,135,580	1,601,685
$\sigma_w/\sigma=$	0.1388	0.6288	0.7202

TABLE 9

BEST FOURTH-DEGREE COEFFICIENTS FOR ESTIMATING VERTICAL INTENSITY AND ITS EVEN VERTICAL DERIVATIVES AT CENTER OF 49-POINT SQUARE ARRAY

$\omega=$	$\eta(0, 0, 0)$	$\eta_{zz}(0, 0, 0)$	$\eta_{zzzz}(0, 0, 0)$
p	$D'a_p$	$D'a_p$	$D'a_p$
0	+863	+3644	+1688
1	+651	+2397	+1014
2	+450	+1194	+ 351
3	+204	+ 63	− 126
4	+ 36	−1008	− 756
5	−279	−2814	−1764
6	+ 89	+ 863	+ 914
7	− 24	+ 12	+ 339
8	−174	−1134	− 504
9	+206	+1646	+1031
$D'=$	4851	19404	9702
$\sigma_w/\sigma=$	0.4218	0.5303	0.6105

TABLE 10

COMPARISON OF ARRAYS FOR FOURTH-DEGREE ESTIMATION OF EVEN VERTICAL DERIVATIVES

			For $\widehat{\eta}_{zz}(0, 0, 0)$		For $\widehat{\eta}_{zzzz}(0, 0, 0)$	
Array	n	$\overline{r^2}$	σ_w/σ	$\mu=\overline{r^2}\cdot\sigma_w/\sigma$	σ_w/σ	$\mu=(\overline{r^2})^2\cdot\sigma_w/\sigma$
012356	21	4.57143	1.443	6.597	2.322	48.53
0123569	25	6.72000	0.6288	4.226	0.7202	32.52
Square	49	8.00000	0.5303	4.242	0.6105	39.07

TABLE 11

NEAR-BEST FOURTH-DEGREE COEFFICIENTS FOR ESTIMATING VARIOUS QUANTITIES AT CENTER OF 21-POINT ARRAY 012356
(For Best Coefficients, See Tables 6–7)

$\omega=$	$\eta(0, 0, 0)$	$\eta_{zz}(0, 0, 0)$			$\eta_{zzzz}(0, 0, 0)$		$\eta^*(0, 0, 1)$		$\eta^*(0, 0, 2)$	
p	$D'a_p$	$D'a_p$	$D'a_p$	$D'a_p$	$D'a_p$	$D'a_p$	$D'a_p$	$D'a_p$	$D'a_p$	$D'a_p$
0	+26	+20	+40	+60	0	+20	+12	+140	+102	+230
1	+15	+12	+11	+23	+6	+ 4	+ 3	+ 60	+ 47	+ 91
2	0	0	0	0	−2	− 2	+ 1	+ 15	− 8	− 8
3	− 6	−21	−26	−47	−7	−13	− 5	− 81	− 75	−163
5	0	0	0	0	+1	+ 2	0	0	+ 4	+ 8
6	+ 1	+ 4	+ 5	+ 9	+2	+ 4	+ 1	+ 16	+ 17	+ 37
$D'=$	66	36	48	84	7	15	12	180	42	90
$\sigma_w/\sigma=$	0.63	1.47	1.46	1.45	2.77	2.34	1.41	1.39	4.95	4.95

TABLE 12

NEAR-BEST SECOND- AND FOURTH-DEGREE COEFFICIENTS FOR ESTIMATING SECOND VERTICAL DERIVATIVE AT CENTER OF 25-POINT ARRAY 0123569
(For Best Coefficients, See Table 8)

$\omega=$	$\eta_{zz}(0, 0, 0)$	
	Second Degree	Fourth Degree
p	$D'a_p$	$D'a_p$
0	+16	+100
1	+14	+ 30
2	+12	+ 17
3	+ 7	− 12
5	− 3	− 77
6	− 6	+ 2
9	−28	+ 15
$D'=$	516	312
$\sigma_w/\sigma=$	0.1388	0.6407

TABLE 13

NEAR-BEST FOURTH-DEGREE COEFFICIENTS FOR ESTIMATING SECOND VERTICAL DERIVATIVE AT CENTER OF 49-POINT SQUARE ARRAY
(For Best Coefficients, See Table 9)

$\omega =$	$\eta_{zz}(0, 0, 0)$
p	$D'a_p$
0	+120
1	+ 68
2	+ 15
3	0
4	− 25
5	− 70
6	+ 22
7	0
8	− 28
9	+ 41
$D' =$	504
$\sigma_w/\sigma =$	0.5373

TABLE 14

NEAR-BEST SECOND-DEGREE COEFFICIENTS FOR ESTIMATING SEVERAL QUANTITIES AT CENTERS OF TWO SMALL ARRAYS
(For Best Coefficients, See Tables 3–5)

ω	Array	n	σ_w/σ	μ	D'	p	$D'a_p$
$\eta(0, 0, 0)$	016	9	0.493	—	42	0	+10
						1	+ 9
						6	− 1
	013	9	0.567	—	17	0	+ 5
						1	+ 4
						3	− 1
$\eta_{zz}(0, 0, 0)$	016	9	0.326	1.45	33	0	+ 4
						1	+ 3
						6	− 4
	013	9	0.825	1.83	10	0	+ 4
						1	+ 2
						3	− 3
$\eta^*(0, 0, 1)$	016	9	0.624	—	12	0	+ 4
						1	+ 3
						6	− 1
	013	9	0.938	—	10	0	+ 6
						1	+ 3
						3	− 2

GEOPHYSICS, VOL. XXI, NO. 1 (JANUARY, 1956), PP. 142–155, 11 FIGS.

REVIEW OF CURRENT DEVELOPMENTS IN EXPLORATION GEOPHYSICS*

MILTON B. DOBRIN† AND ROBERT G. VAN NOSTRAND†

ABSTRACT

During the past year, exploration geophysics has made its greatest progress in the application to prospecting of instruments and techniques which were until recently only in the development stage. The most notable examples are magnetic recording and velocity logging, both of which are already being offered as commercial services. The use of magnetic recording permits greater flexibility in seismic interpretation; automatic time correction, facilitating compositing as well as preparation of record sections; and the ready storage of seismic data in a form suitable for any processing procedures that may be developed in the future. Interval velocity logs have given geophysicists a better understanding of the origin of reflections from a complexly layered section. This understanding should lead to a more realistic interpretation of reflection data, and may eventually make it possible to map stratigraphic as well as structural features. Other noteworthy developments in seismic prospecting during 1955 include new methods for generating seismic energy, novel approaches to the improvement of signal-to-noise ratio, and the application of high frequency techniques in oil exploration.

Although current research in petroleum geophysics is concentrated more than ever on seismic techniques, there have been important developments in the application of other geophysical methods to petroleum prospecting, mining exploration, and engineering problems. The gamma-gamma logger now gives density data which are sufficiently reliable for gravity interpretation; an induced polarization method has been successful in finding ground water; and airborne electromagnetic methods have been widely used in the search for base metals in Canada. A new type of airborne magnetometer based on nuclear magnetic resonance has gone into service in prospecting for iron ore in the western United States. This device is particularly adapted for use in light aircraft.

The rapidity of current technological improvement in exploration geophysics is attributed to the acceleration of geophysical research activity in the oil industry after World War II, to productive fundamental research, and to a widespread attitude among geophysicists of dissatisfaction with existing techniques.

INTRODUCTION

For the past seven years, the SEG Committee on Geophysical Activity has reported on the nature and extent of geophysical exploration activity during the previous year. This paper, sponsored by the SEG Research Committee, reports on geophysical activity of a somewhat different kind. In it we shall review the more important *technical* advances that have been made in exploration geophysics during the past year. This has been a particularly fruitful period for geophysical research and development, and it is unfortunate that space will not allow us to do justice to all of the significant contributions in the field.

To future historians reviewing the progress of exploration geophysics, the current year may well be noteworthy for the rapidity with which important new developments, previously confined to research laboratories, were put to extensive use in actual exploration. In many ways we are in the midst of a technologi-

* Sponsored by the Special Committee on Research of the SEG. Presented before the Society at its Annual Meeting in Denver October 4, 1955. A somewhat different version was presented by the junior author before the European Association of Exploration Geophysicists at its meeting in London on December 8, 1955. Manuscript received by the Editor October 21, 1955.

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cal revolution which is very likely attributable to the tremendous expansion in the geophysical industry's research activity after the Second World War.

The most significant advances have been made in the field of seismic prospecting. Until a very few years ago, technological progress in this field was rather slow, involving, for the most part, refinements of the same basic techniques and equipment which had been employed since the early days of seismic exploration. Then, beginning about 1951, a number of new developments came out of the oil industry's research laboratories which promised to revolutionize the seismic art and to increase its effectiveness in finding oil. Of these developments, two of the most significant were magnetic recording and acoustic velocity logging. Both of these tools have gone into extensive service in actual exploration and the past year has seen an almost explosive growth in the use of each.

MAGNETIC RECORDING

Let us first consider the status of magnetic recording. Figure 1 presents some interesting information on the total number of magnetic recording units

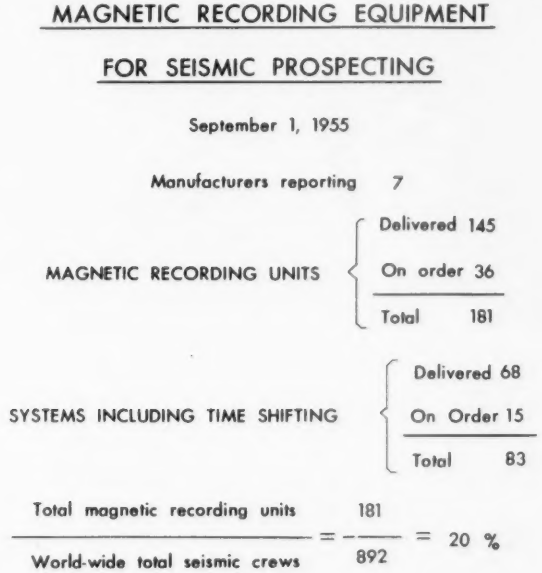

FIG. 1. Statistics on the production of magnetic recording units up to September 1, 1955.

that are in service, or are about to go into service, for geophysical work. These statistics are based on a survey made among manufacturers of magnetic equipment. They show that 145 units have been delivered and that 36 units are on

order. When the equipment now on order is delivered, one recording unit will be in service for every 5 seismic crews operating in the first half of 1955. A large majority of these units have been manufactured during the past year.

Almost half of the playback units in service have heads with adjustable time delay. Thus, a large proportion of existing magnetic playbacks are capable of turning out seismic records of a type that cannot be obtained at all with conventional recording equipment. Specifically, the time shifting makes it possible to adjust for time delays, caused by weathering, elevation, and normal moveout,

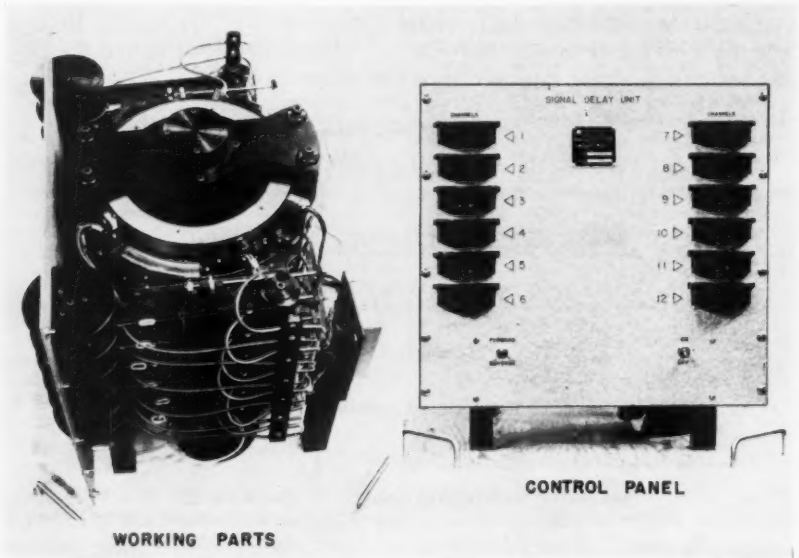

FIG. 2. Static time shifting unit built by Engineering Research Associates. Magnetic drum in the center rotates at 25 rpm. Head at the right records; middle head, at a position which is set at the control panel to give the desired time delay, picks up the signal and passes it on to the mixer; and the fixed head at the left erases the signal.

individually on each trace. This feature is particularly valuable when traces are composited, since mixing of uncorrected traces often causes cancellation of reflections rather than reinforcement. In some areas of poor reflection quality, the availability of time-shifting equipment might make the difference between mapping and missing a key reflection in a critical zone.

Two kinds of time shifters are available. The static type keeps the same time difference between traces all through the playback of a record. Figure 2 shows how one such shifter, built by Engineering Research Associates, operates. Three heads are spaced around a magnetic drum which rotates at 25 rpm. One head

records the signal from a regular tape playback unit; another head, at a position which is set manually to give the desired time delay, picks up the signal and passes it on to the mixer and then to the recording camera; and the third head, which is fixed, erases it altogether.

The static time shifter has the disadvantage that it can fully correct for normal moveout at one time on the record only. To correct for the moveout

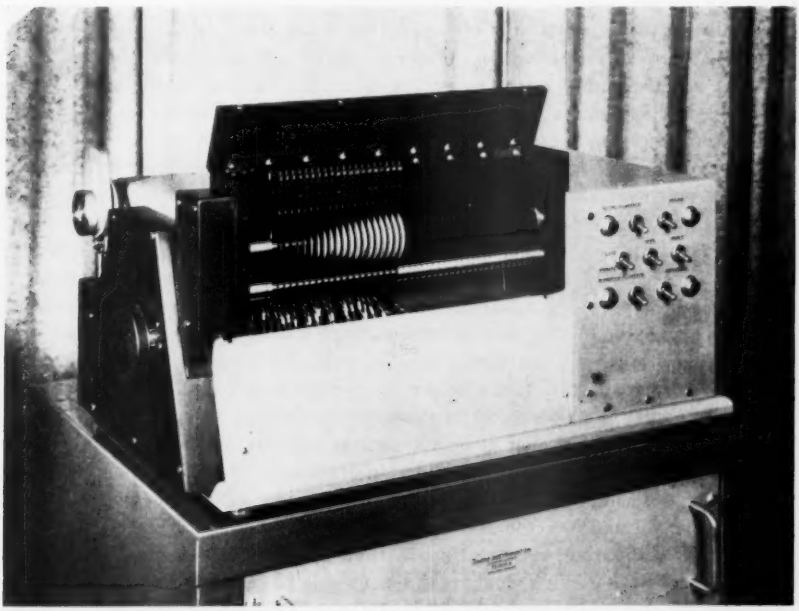

FIG. 3. Continuous time-shifting device built by Techno Instrument Company. Spread correction is set with the dial at the left end of the case; the velocity function is entered into the machine by means of the cam at the left (at the corner of the case). This and the cams below the individual playback heads govern the rate at which the time shift is varied for each trace during the playback of a magnetic record.

as it varies down the record, a special type of shifter is necessary that can move the respective heads mechanically during playback according to a formula based on the velocity function. One device of this type (Figure 3) has just been put on the market by the Techno Instrument Company. The main shaft rotates in synchronism with the magnetic tape drive during playback and the relative positions of the individual magnetic heads are shifted during the rotation by the respective step-out cams associated with each. A separate cam is cut for each velocity function and a setting for spread length is made with a special knob.

In addition to time shifters, several other devices have been developed for processing seismic data recorded magnetically. Among these are time domain, or delay line, filters. In a filter of this type the signal is picked up from a drum surrounded by a number of spaced heads with adjustable sensitivities. The weighted outputs of the heads are added, the resultant signal having a spectrum depending on the individual sensitivity settings. This procedure gives great flexibility in filtering but it is practical only if the traces are played back sequentially. Another data-handling operation made more feasible by magnetic recording is trace multiplication. Under favorable circumstances, this will give a better signal-to-noise ratio than trace addition. Because of the great phase sensitivity which enters into multiplying signals, time shifting of the traces before multiplication is especially important.

Magnetic recording is still so new that there is a wide variation in attitudes among geophysicists as to its place in seismic exploration. Some look upon it only as a tool for research studies which require exceptional flexibility in data storage. At its present stage, they feel that it is too expensive for exploration work. Others believe that magnetic tape justifies its cost only in certain problem areas. They recognize the advantages, where stratigraphy or structure is complicated, of being able to play records back through a wide variety of filters without having to worry about the shot-point variable. Also, where record quality is poor the ability to shift times before compositing may well improve records enough to justify the added cost of magnetic equipment.

To an increasing number of geophysicists, however, magnetic recording appears desirable for *all* seismic shooting. In their opinion, it is important to be able to store seismic data covering the entire range of usable frequencies in reproducible form. From the standpoint of economics, such storage could save the cost of reshooting at some future time if new data-handling procedures should be developed which would make it possible to get more or better information from seismic shooting than is presently obtainable. This viewpoint involves something of a gamble since there is no guarantee that such improvements will ever appear, but geophysicists have gambled before and won.

ACOUSTIC VELOCITY LOGGING

Closely related in importance to magnetic recording is acoustic velocity logging. Here also activity has grown tremendously during the past year or so. Of the four loggers developed for use in oil wells by Magnolia, United Geophysical, Humble, and Shell, the first two are available to the industry on a service basis; the other two have been recently licensed to well logging companies which should be offering service with them in the near future. As of mid-September, 1955, 661 wells had been logged for velocity, 334 of them by oil companies using their own instruments, and 327, almost an equal number, on a service basis by contractors; 407 of these logs were run in the United States and 254 outside this country, mostly in Canada.

At the outset, most velocity logging devices were designed primarily for getting seismic velocity information more conveniently than with conventional well shooting. As experience has been gained with them, however, many additional uses have become apparent which may turn out to be more important. In some areas, correlation has been more satisfactory with velocity logs than with any other type of log. Figure 4 shows an example of such correlation over a distance of 30 miles in Andrews and Midland Counties, Texas.

Often a velocity log will give the geologist a more reliable basis for picking a formation top than an electric log in the same hole. Figure 5 shows how the

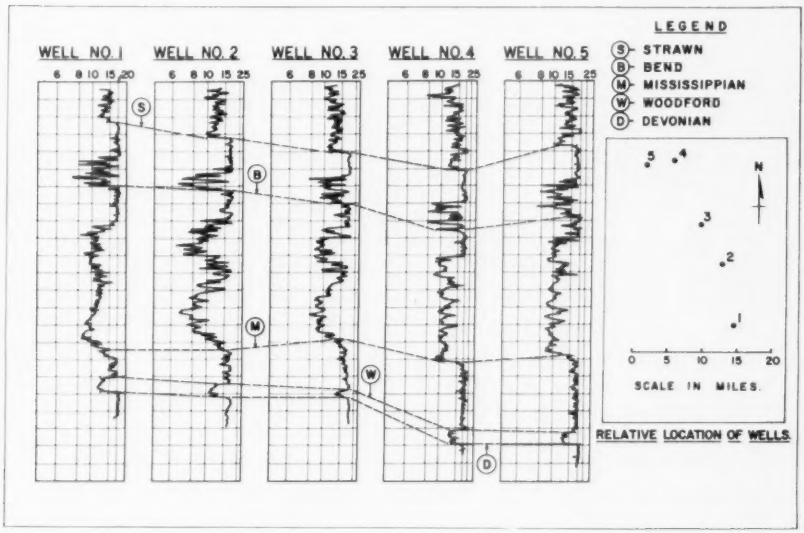

FIG. 4. Correlation of velocity logs from wells over a thirty-mile distance in Andrews and Midland Counties, Texas. Logs are adjusted to sea-level datum, so that the structural relationship is correct.

contrast in velocity at the top of the Buda formation in Gonzales County, Texas is much more distinctive than the contrast in resistivity or self-potential at the same interface.

A very recent and highly promising use of velocity logs is in the identification of oil and gas bearing sands. This application was proposed by Warren Hicks, of Magnolia Petroleum Company, in a paper presented before the SEG at its 1955 Annual Meeting. It has been demonstrated both in the laboratory and in boreholes that sands saturated with oil or gas have a lower acoustic velocity than the same sands when saturated with water alone. The electrical resistivity, on the other hand, of a sand saturated with oil or gas is higher than that of the same

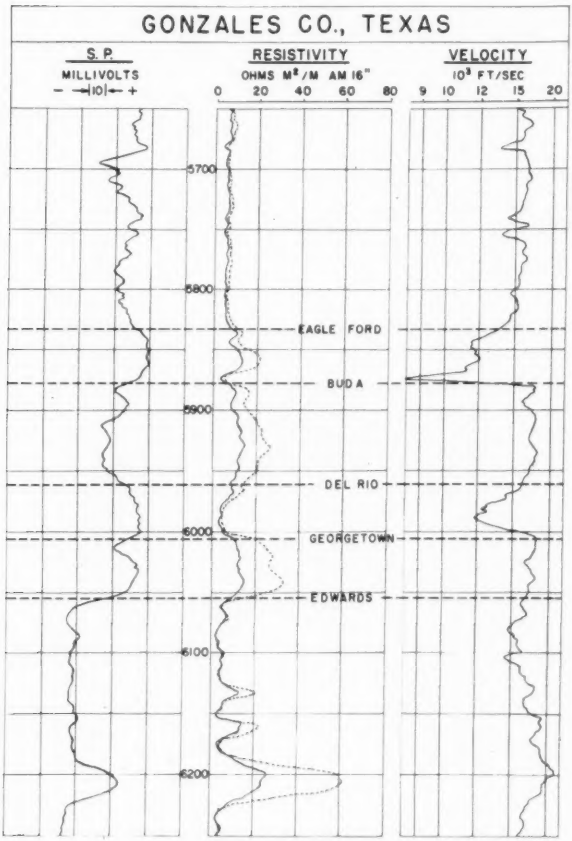

FIG. 5. Velocity, resistivity, and self-potential logs in a well in Gonzales County, Texas. Velocities are in thousands of ft/sec. Distance between successive horizontal lines represents depth interval of 100 ft.

sand when saturated with water. Thus it should be possible to locate an oil- or gas-bearing sand by using a velocity log in combination with an electric log. When one passes from a water sand into an oil or gas sand, the velocity should decrease and the resistivity should increase. A lowering of porosity would also yield a higher resistivity but the velocity would then show an increase rather than a decrease.

The greatest potential usefulness of velocity logs lies, however, in the improved insight they can give us on the origin of seismic reflections. Such an insight should enable us to put the entire process of seismic interpretation on a sounder

and more satisfactory basis. Interval velocity logs show us that the variation of elastic properties with depth in the earth is much more complex than has been generally realized. Within a vertical distance corresponding to a wavelength, there is usually a large number of contrasts in velocity. A study of these features leads us to the realization that the reflections we actually see on seismic records represent a composite of events from these many individual interfaces. What we call reflection character depends most critically on the thicknesses and velocities ef the respective individual strata. Small variations in the spacing or elastic characteristics of these beds may cause substantial changes in character.

A particularly striking method of analyzing the relation between the velocity layering and reflection character is by seismogram synthesis from velocity logs. Peterson and his associates at United Geophysical Corp. have made up realistic-looking artificial seismograms by converting the velocity logs to variable area film strips, running the strips past a photoelectric cell, and recording the resultant signals after they are passed through appropriate filters. Others have carried on a similar type of synthesis with laboratory models of the earth in which velocity contrasts are represented by changes in the inside diameter of long pipes or in the over-all diameter of long solid rods.

These studies may have an important bearing on the problem of interpreting reflection character in terms of lithology. If we could work out reliable techniques for doing this, we would be well on the way to being able to find stratigraphic traps with the seismograph.

HIGH-FREQUENCY SEISMIC RECORDING

An important consequence of this type of study has been a better understanding of the frequency characteristics of waves reflected from various formations. We need such an understanding if we are to take full advantage of the great flexibility in filtering that we can get with magnetic records. Where the layering is thin, for example, the best reflection information can often be obtained at frequencies which are much higher than those conventionally used in seismic work.

One company, Geophysical Service Inc., is offering contract service with special equipment which operates only in the range from 55 to about 300 cps. Originally designed for mining and engineering investigations at shallow depths, this system has turned out to give unexpectedly useful information in oil exploration. In areas of complex structure, the use of high frequencies with close geophone spacing has made it possible to map steep dips, overthrusting, and unconformities within the first few thousand feet of section. Such features could not ordinarily be resolved by conventional shooting techniques. High frequencies have also been used for detailing shale bodies surrounded by sand. In general, shale is much more homogeneous than sand and contains few if any reflecting interfaces. The sand, on the other hand, will usually be interspersed with thin shaly zones which are so closely spaced that they give reflections that can be

detected only through high-frequency filters. On a high-frequency seismic record, then, a thick shale section should be represented by an absence of reflections and a sand section by a high density of reflections. Figure 6 shows a seismic cross-section obtained by a GSI "High-Resolution" crew in Gonzales County, Texas. Here the configuration of the middle Wilcox shale was determined on the basis of reflection density. The thickening or thinning of the shale between wells as

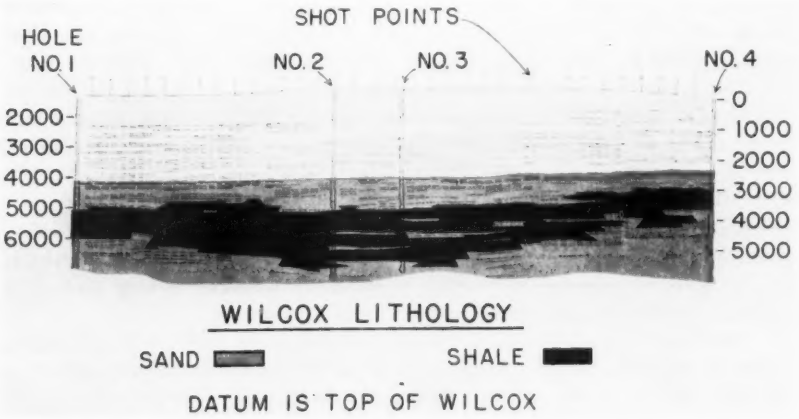

FIG. 6. Seismic cross-section obtained by a GSI "High Resolution" crew in Gonzales County, Texas. Dark part of section is region of no reflections and is interpreted on the basis of electric logs as being shale.

indicated by the electric logs is reflected in the shape of the reflection-segment envelope corresponding to the sand-shale boundary.

PRESENTATION OF SEISMIC DATA

During the past year, the geophysical industry has put much effort into the improvement of methods for presenting seismic data. Record sections have been particularly popular because they aid the interpreter in visualizing his subsurface picture and also because they make it easy to present raw seismic data to the geologist and exploration executive in a form that conveys the most information.

The Reynolds plotter was developed to transform traces on seismic records into a form more suitable for presentation in a vertical cross-section. A complex optical system shifts the signals along a time axis to compensate for weathering, elevation, and normal moveout. It also transforms the time scale on the records to a depth scale on the section. Figure 7 shows a Reynolds record section made from records originally shot on magnetic tape in Southern Louisiana. The section gives evidence of a small fault in the Frio at a depth of about 10,000 ft. The record was played back from the tape through a high frequency filter, and

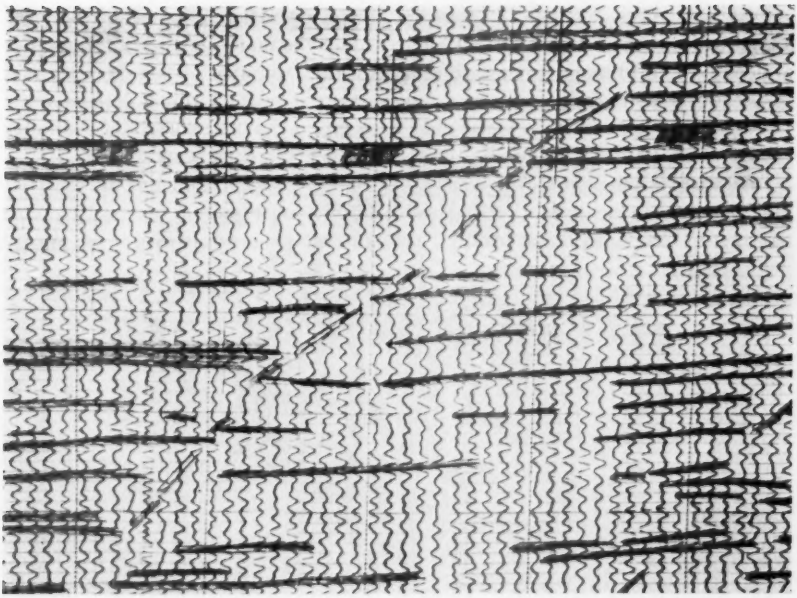

FIG. 7. Record section made with Reynolds plotter from records originally recorded on magnetic tape in Southern Louisiana. Section is traversed by a small fault. Courtesy of National Geophysical Company and Sunray-Mid-Continent Oil Company.

the section indicates the usefulness of such frequencies in resolving faults with a small throw.

The "dynamic" head shifter on magnetic playback units also makes it possible to construct record sections on which normal moveout and other irregularities are removed. Figure 8 shows a portion of a record section made with Sun Oil Company's dynamic head shifter which yields a cross-section on a time rather than a depth scale. The time-shifting corrects for moveout so effectively that reflections at four or five tenths of a second can be followed. These would normally have such a large stepout that they could be correlated only with great difficulty.

One oil company is experimenting with record sections on variable density film. These should look more like geological-cross sections than any which use the conventional type of presentation.

OTHER SEISMIC DEVELOPMENTS

Several other important developments in seismic prospecting should be mentioned. The "thumper," or Geograph, which generates seismic energy by dropping a 3-ton weight on the earth, has seen increasing use during the past year,

and at least seven "thumper" crews are now in operation. Because of the large amount of magnetic tape required for recording the many individual drops that are composited to make up each final record, the "thumper" operations are said to use up more than half of all such tape that is manufactured. Recently the system has gone to sea. The weight has been dropped on the surface of the water in Galveston Bay and, according to reports, has given good records there.

Because of an increase in reconnaissance-type exploration during the past year or so, there has been a resurgence of activity in refraction prospecting. One contractor, Geophysical Service Inc., has six refraction crews in operation, mostly

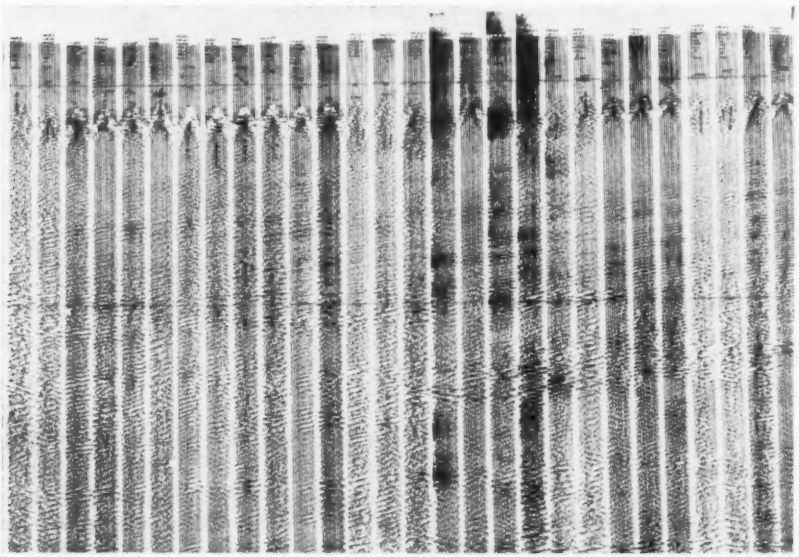

FIG. 8. Record section made with Sun dynamic head shifter. Horizontal line across records represents time of 1 second. Original recording was made on magnetic tape in South Texas. Courtesy of Sun Oil Company.

outside the U. S. This work is carried on with a new geophone and recording system that make it possible to go to frequencies as low as 2 cps.

GRAVITY, MAGNETIC, AND ELECTRICAL PROSPECTING

In gravity prospecting, new developments have not been as numerous over the past year as in the seismic field. A new and improved model of the gamma-gamma density logger has been constructed and the data it gives appear to be generally adequate for gravity interpretation but not for porosity determination. Evaluation of this tool by a number of oil companies is continuing on a coopera-

tive basis. Meanwhile it is being used operationally in many areas to get density data for gravity work.

Last winter, the first gravity contour map to have been constructed in a *vertical* plane was presented at the Annual Convention of the A.I.M.E. in Chicago. The data for this map, which is shown in Figure 9, were obtained by William Allen, of Phelps-Dodge, in the shafts and adits of a copper mine near Bisbee, Arizona. The pronounced high-gravity axis is shown to project into the unexplored area, suggesting the direction that further development of the mine property should take.

In magnetic prospecting, one development of the past year is particularly

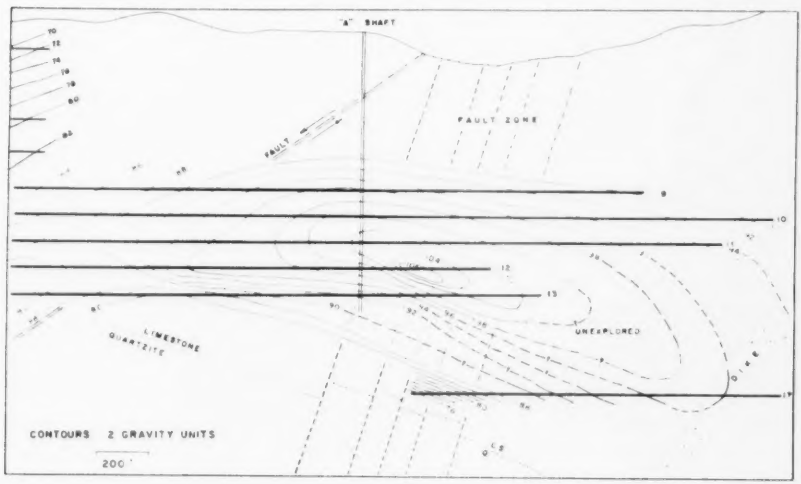

FIG. 9. Vertical gravity map made by William Allen, Jr. for Phelps-Dodge in a copper mine near Bisbee, Arizona. Published by permission of the American Institute of Mining, Metallurgical, and Petroleum Engineers.

worthy of mention. At the St. Louis meeting of the SEG in April, 1954, Martin Packard, of Varian Associates, presented a paper describing a new type of magnetometer based on nuclear magnetic resonance. This instrument could measure absolute earth fields in the laboratory with an accuracy of one gamma. Within the past few months, this magnetometer has been adapted for operation in a light airplane and is now being used in actual surveys for iron ore in Northern California. The installation consists of a small bird towed at the end of an 80-ft cable. The bird contains only a magnetic coil and a 1-liter bottle of water.

Figure 10 shows a sample record made with this device. Readings are recorded once a second, and the full-scale sensitivity of 150 gammas gives data quite comparable to what can be obtained from fluxgate-type magnetometers.

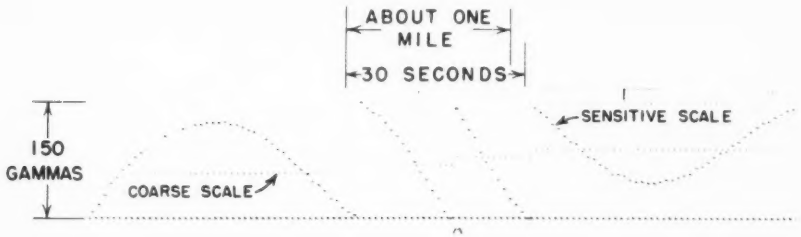

FIG. 10. Sample record of the Varian airborne magnetometer using nuclear magnetic resonance. Energizing current is applied for one-half second and output is measured for next half-second, resulting in closely spaced but discontinuous signals on record. Courtesy of Varian Associates.

In electrical prospecting, the most noteworthy trend of the past year has been a rapid increase in the number of airborne electromagnetic surveys for base-metals. Two contract companies, Aeromagnetic Surveys, Ltd. and Hans Lundberg, Ltd., have been offering this service and at least two mining companies have been making electromagnetic surveys from their own planes. Figure 11 shows a typical installation on a plane equipped for electromagnetic, magnetic,

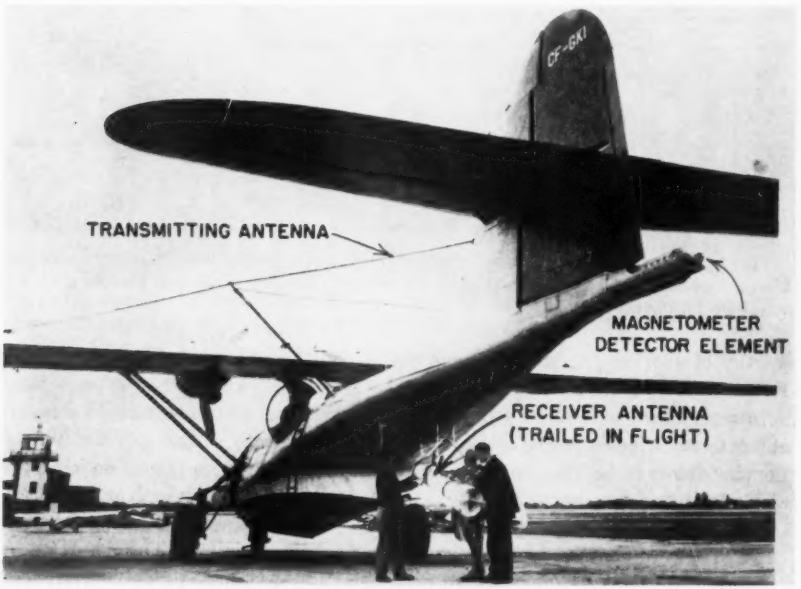

FIG. 11. PBY equipped with apparatus for electromagnetic, magnetic, and radioactivity surveying. Scintillation counters are mounted in the hull. Courtesy of Aeromagnetic Surveys, Ltd.

and radioactivity measurements. The transmitting antenna is stretched across the wings and the receiving antenna is trailed in flight. Flight altitude is generally about 500 ft and fields are recorded at two frequencies, 400 cps and 2,300 cps.

Promising advances have been made in electrical exploration for ground water by Prof. Vacquier, of the New Mexico Institute of Mining and Technology, who has developed an induced polarization method for this purpose. His technique seems particularly suitable for determining the depth of the water table in desert areas.

FUNDAMENTAL STUDIES

In the foregoing discussion, limitations of space have prevented us from reviewing the important fundamental research going on in geophysics at universities, in government institutions, and in endowed laboratories. Some of this work may well lead to improvements in exploration techniques. The principle of nuclear magnetic resonance, for example, was discovered in university laboratories only a few years ago and it is already being used in the search for iron ore. Some of the geophysical research at academic institutions is being supported by the oil industry. One example is the work of the Geophysical Analysis Group at MIT which is investigating statistical techniques for improving seismic reflection data.

CONCLUSIONS

It would appear from the foregoing examples that progress has been made at an exceptional rate in all branches of exploration geophysics during the past year. Part of this progress is attributable to the aggressive support that the oil industry has been giving to geophysical research. An equally important part may be attributable to a widespread attitude among geophysicists of healthy dissatisfaction with existing ways of doing things. To quote from George Bernard Shaw, "The reasonable man adapts himself to the world; the unreasonable one persists in trying to adapt the world to himself. Therefore, all progress depends on the unreasonable man." Let us hope that the geophysical profession keeps its share of unreasonable people so that our present rate of geophysical progress will continue long into the future.

GEOPHYSICS, VOL. XXI, NO. 1 (JANUARY, 1956), PP. 156–178

NON-TECHNICAL PAPERS

INDEX OF WELLS SHOT FOR VELOCITY

(Fourth Supplement)

V. U. GAITHER

ABSTRACT

This is the first supplement to the Index published in booklet form in 1953. Information is listed on 1,072 well velocity surveys not heretofore reported in any previous publication. Most of these are new surveys shot since July 1952, including those shot in 1953, 1954 and a few in 1955. Corrections and additional information on 37 previously listed surveys are also tabulated.

INTRODUCTION

This is the first supplement to the "Index of Wells Shot For Velocity," published in booklet form in 1953, which included the original Index published in the October 1944 issue of GEOPHYSICS and three later supplements. The preparation of this supplement would not have been possible without the cooperation of the various oil companies, associations and individuals, who responded so willingly when solicited for velocity information. This splendid cooperation indicates that the Index has proved to be of practical value to the geophysical industry as a whole.

The first portion of this supplement gives surveys shot since the 1953 publication and other previously unreported wells. Most of these are surveys shot since July 1952. In the latter portion, shown in italics, are corrections and additional information on previously listed surveys.

Although every effort has been made to show each survey listed in the index as factual, some errors are expected to be discovered. It is requested that all such errors, after careful checking, be reported to the Business Manager of the Society. Also, the omission of information on wells listed should be reported.

ACKNOWLEDGMENTS

The writer is grateful to Mrs. Evelyn Ledeker and Mrs. Dolores Corbin for their assistance in the necessary task of reconciling and assembling information from the various sources.

NOTE: Reprints of this supplement may be obtained from the Business Office at fifty cents per copy. The Index, published in 1953 is also available at $2.50 per copy.

INDEX OF WELLS SHOT FOR VELOCITY

(Fourth Supplement)

STATE OF ALABAMA

County	Company	Lease	Location	Survey Depth	Shot by	Date	Sponsored by
Escambia	California	No. 1 Jones	Sec. 3, 1N-12E	5,710	Southern	1952	Calco
Escambia	Sunnyland	No. 1 Kelley	8, 3N- 9E	5,950	WGC	1953	Calco
Escambia	Durbin, Bond	No. 1 Hufford	11, 2N- 9E	6,216	WGC	1953	Calco
Mobile	Gulf Refining Co.	No. 1 U. S. Steel Corp.	1,788S-9,451W-NE Cor., 26, 3S - 1W	8,203	WGC	1954	Calco
Mobile	Gulf Refining Co.	No. 1 U. S. Steel Corp.	20, 3S - 1W	8,203	WGC	1954	Gulf-Calco

STATE OF ARIZONA

Apache	Shell	No. 1 East Boundary Butte	Sec. 6, 41N-29E	6,481	Shell	1954	Shell

STATE OF ARKANSAS

Franklin	Arkansas-Louisiana Gas	No. 1 Freiburg	Sec. 15, 9N-28W	4,746	Okla. Seis. Co.	1953	Magnolia
Sebastian	Western Nat. Gas-Conoco	No. 1 Bergcamp	1, 7N-30W	8,316	Okla. Geop. Co.	1953	Western Nat.-Conoco
Union	California	No. 1 Smith	29, 18S-17W	8,300	GSI	1952	Calco
Woodruff	Magnolia	No. 1 Roy Sturgis	30, 9N- 3W	5,988	Magnolia	1954	Magnolia

STATE OF CALIFORNIA

Butte	Humble	No. 2 Parrott Invest. Co.	3,941N-4,469W-SE Cor., 4, 19N- 1W	6,698	Humble	1954	CWVSG
Colusa	Humble	No. B-1 Capitol Co.	Sec. 3, 16N- 1W	10,128	Ray	1953	CWVSG
Fresno	LeBow-McNee	No. 1 Miller-Lux	31, 11S-14E	7,000	GSI	1953	CWVSG
Fresno	Standard	No. 63-27F	1,650S-1,650W-NE Cor., 27, 20S-16E	8,670	Lane-Wells	1954	CWVSG
Fresno	Western Gulf	No. 22-4 Lillis	Sec. 4, 17S-14E	4,650	Texas	1949	CWVSG
Glenn	Humble	No. 1 H. C. Fredricksen	110S - 875W-NE Cor., 16, 20N- 3W	11,635	Humble	1954	CWVSG
Kern	Tide Water	No. 65-A-20 Core Hole	Sec. 20, 27S-21E	4,000	Western	1953	CWVSG
Kern	Tide Water	No. 63-8 SF&FL	Sec. 8, 25S-20E	5,495	GSI	1953	CWVSG
Kern	Gen. Petroleum	No. 15-24 Giumarra	330S - 330W-½ Cor., 24, 30S-28E	10,506	Western	1954	CWVSG
Kern	Geochemical	No. 33 "Standard"	1,650S-3,803W-NE Cor., 1, 25S-22E	4,389	Western	1954	CWVSG
Kern	Standard	No. 26 Buck Comm.	Sec. 28, 29S-29E	5,389	Gulf	1948	CWVSG
Kern	Gen. Petroleum	No. 38-23 KCL	Sec. 23, 29S-25E	12,613	Western	1949	CWVSG
Kern	Standard	No. 4-2 SF&FL	Sec. 12, 25S-19E	12,000	United	1949	CWVSG
Kern	Shell	No. 37-4 KCLA	Sec. 4, 30S-25E	10,436	Shell	1949	CWVSG
Kern	Superior	No. 4 OLC	Sec. 26, 26S-19E	12,900	United	1949	CWVSG
Kings	Shell	No. 1-1 Fresno Slough Unit	Sec. 1, 18S-19E	8,486	Shell	1949	CWVSG
Los Angeles	Shell	No. 1 Hart	Sec. 29, 4S-12W	10,091	Shell	1948	CWVSG
Los Angeles	Shell	No. A-3 Puente	Sec. 35, 2S-10W	5,010	Shell	1949	CWVSG
Madera	Shell	No. 4 Merced-Madera Strat Test	340N-2,310W-E½ Cor., 35, 10S-15E	6,345	Shell	1953	CWVSG
Madera	Shell	No. 7 Merced-Madera Strat Test	330N- 330E-SW Cor., 31, 11S-16E	7,055	Shell	1953	CWVSG
Madera	Shell	No. 9 Merced-Madera Strat Test	2,710S - 330E-NW Cor., 23, 11S-16E	5,950	Shell	1953	CWVSG
Madera	Shell	No. 10 Merced-Madera Strat Test	630S - 330E-NW Cor., 28, 12S-17E	6,774	Shell	1953	CWVSG
Madera	Shell	No. 8 Merced-Madera Strat Test	330N-1,000W-E½ Cor., 2, 10S-15E	5,163	Shell	1953	CWVSG
Madera	Shell	No. 11 Merced-Madera Strat Test	330S - 330E-NW Cor., 3, 10S-14E	7,290	Shell	1954	CWVSG
Madera	Shell	No. 35 Merced-Madera Strat Test	1,680N- 350E-SW Cor., 33, 9S-16E	4,088	Shell	1954	CWVSG
Madera	Shell	No. 14A Merced-Madera Strat Test	475N- 330E-SW Cor., 29, 11S-16E	7,580	Shell	1954	CWVSG
Madera	Shell	No. 36 Merced-Madera Strat Test	660N- 330W-SE Cor., 1, 11S-16E	4,956	Shell	1954	CWVSG
Madera	Shell	No. 4 W. Chowchilla Strat Test	1,980N- 660W-SE Cor., 24, 10S-13E	6,008	Shell	1954	CWVSG
Merced	Standard	No. 51 Redfern	Sec. 28, 11S-12E	13,003	GSI	1953	CWVSG
Merced	Richfield	No. 2 Fancher Core Hole	Sec. 30, 8S-15E	4,371	Western	1953	CWVSG

County	Company	Lease	Location	Survey Depth	Shot by	Date	Sponsored by
Merced	Shell	No. 55 Redman	Sec. 10, 10S-13E	6,023	Shell	1953	CWVSG
Merced	Shell	No. 2 Merced-Madera Strat Test 1,650S-1,650E-NW	Cor., 22, 9S-14E	4,623	Shell	1953	CWVSG
Merced	Shell	No. 12 Merced-Madera Strat Test 2,800S- 330W-NE	Cor., 20, 8S-13E	7,580	Shell	1953	CWVSG
Merced	Shell	No. 15 Merced-Madera Strat Test 660N- 660E-SW	Cor., 20, 8S-14E	5,894	Shell	1953	CWVSG
Merced	Shell	No. 16 Merced-Madera Strat Test 2,300S- 330W-NE	Cor., 1, 9S-14E	4,922	Shell	1953	CWVSG
Monterey	Texas	No. 1 Floyd Patterson 300S-1,650W-NE	Cor., 20, 23S-9E	2,462	Western	1954	CWVSG
Monterey	Barnsdall	No. 1 R&W	Sec. 21, 23S-12E	4,095	United	1948	CWVSG
Orange	Shell	No. 19 Olinda 2	Sec. 17, 3S-9W	3,780?	Shell	1948	CWVSG
Orange	Amerada	No. 63-1 Irvine	Sec. 27, 5S-9W	3,880	Amerada	1949	CWVSG
Orange	Shell	No. 5-22 Kettler	Sec. 22, 5S-11W	9,250	Amerada	1949	CWVSG
Sacramento	Union-Dow	No. 1 Attorney General	Sec. 13, 7N-5E	3,950	United	1953	CWVSG
Santa Barbara	Union	No. 18 Dome	Sec. 24, 9N-34W	11,256	United	1953	CWVSG
Santa Barbara	Los Nietos	No. 25-11 W. Gulf SS&T	Sec. 11, 9N-34W	9,437	United	1953	CWVSG
Santa Barbara	Amerada	No. 1 Tognazzi	Sec. 14, 8N-33W	8,600	United	1948	CWVSG
Santa Barbara	Richfield	No. 1 Perkins	Sec. 27, 10N-26W	11,860	Western	1949	CWVSG
San Luis Obispo	Sunray	No. 63-5 G. P. Wreden	Sec. 5, 29S-18E	10,970	Western	1953	CWVSG
San Luis Obispo	Texas	No. 1 Clarke NCT	Sec. 15, 27S-14E	4,325	Amerada	1955	CWVSG
San Luis Obispo	Texas	No. 1 Commatti Ranch 7,584N-1,961W-SW	Cor., 10, 28S-16E	6,500	Amerada	1955	CWVSG
San Luis Obispo	Union	No. 1 Wreden	Sec. 17, 29S-17E	5,700	Western	1948	CWVSG
San Luis Obispo	Union	No. 5 Wreden	Sec. 5, 29S-18E	6,650	Western	1949	CWVSG
San Joaquin	Standard	No. 1 Patterson Const. Co. 850N-1,250W-SE	Cor., 30, 5N-5E	8,997	Western	1954	CWVSG
San Joaquin	Shell	No. 1 Pacific States	Sec. 9, 2N-5E	5,460	United	1949	CWVSG
Sonoma	Tide Water	No. 1 Noble	Sec. 29, 4N-5W	7,135	GSI	1953	CWVSG
Stanislaus	Standard	No. 1 Young Comm.	Sec. 34, 3S-8E	13,671	Western	1953	CWVSG
Sutter	Standard	No. 1 Rossi	Sec. 15, 12N-2E	5,340	GP	1953	CWVSG
Sutter	Marshall Brown	No. 1 Montna 50S- 440W-NE	Cor., 35, 13N-3E	5,726	GSI	1954	CWVSG
Sutter	Humble	No. 1 Sutter Basin Corp. 1,556N-1,486E-SW	Cor., 24, 13N-2E	7,250	Humble	1954	CWVSG
Tehama	Continental-W. Gulf	No. 1 USL 1,520S-1,520W-NE	Cor., 24, 29?-3W	7,870	Western	1954	CWVSG
Ventura	Humble	No. 1 Limoneira	Sec. 23, 3N-22W	15,474	Western	1953	CWVSG
Ventura	Standard	No. 1 Lucas 600S-1,500W-NE	Cor., 12, 1N-22W	9,600	GSI	1954	CWVSG
Ventura	Texas	No. 1 Hunter River Ranch NCT-1 330N-1,320E-Center,	36, 4N-20W	10,070	Western	1954	CWVSG
Ventura	Shell	No. 2 SPC 2,538N-2,740W-SE	Cor., 29, 3N-21W	12,000	GSI	1955	CWVSG
Ventura	Humble	No. 2 Berylwood Invest. Co.	Sec. 32, 3N-20W	6,700	Amerada	1949	CWVSG
Yolo	Humble	No. 1 J. C. Maxwell	Sec. 7, 7N-3E	13,000	GSI		CWVSG
Yolo	Standard	No. 1 E. C. Dwyer	Sec. 21, 7N-4E	8,200	Southern		CWVSG
Yolo	Standard	No. 1 C. Walker Est.	Sec. 10, 11N-1E	6,248	Southern	1953	CWVSG
Yolo	Western Gulf	No. 1 J. M. Bemmerly 990S- 33E-NW	Cor., 36, 11N-1W	3,985	Western	1954	CWVSG
Yolo	Shell	No. 25X-8 Madison Strat Test 2,250N-1,320E-SW	Cor., 8, 10N-1E	5,491	Shell	1953	CWVSG
Yolo	Shell	No. 1-1 Saxon Unit	Sec. 7, 7N-3E	5,950	United	1948	CWVSG

STATE OF COLORADO

Adams	Sinclair	No. 1 Goedert NE NE SE	24, 1S-59W	6,360	GSI	1954	Sinclair
Arapahoe	Warren	No. 1 Hart NW NW SW	34, 4S-62W	5,547	Carter	1952	?
Archuleta	Stanolind-Southern	No. 1 Ute	22, 32N-3W			1953	Stanolind
Douglas	California	No. 1 State J. S. Abercrombie	16, 8S-67W	10,687	Southern	1953	RMSWSA
Jackson	Hiawatha	No. 1-25 Gov't. SW SW SW	25, 7N-81W	7,650	Hiawatha	1953	Hiawatha
La Plata	Great Western Drilling	No. 1 Lewis School Land	3, 34N-11W			1953	Stanolind
Larimer	California	No. 1 Hummel	3, 6N-68W	7,882	SSC	1954	Calco
Moffat	Texaco	No. 1 Gov't Scott	30, 5N-95W	6,006	Texaco	1955	Texaco
Montezuma	Hathaway Bros.	No. 1 Lyom Federal	11, 37N-20W	7,440	Shell	1951	Shell
Montezuma	Conoco	No. 1 Ute Mountain	7, 32N-19W	7,208	Century	1954	Conoco
Montezuma	Skelly	No. 1 Benton	15, 33N-13W	10,390	Century	1953	Skelly
Morgan	Lion	No. 1 Twin T. Nicklas C SW NW	10, 6N-57W	7,500	Tomlinson	1954	RMSWSA
Sweetwater	El Paso Natr. Gas Co.	No. 1 Morrow Creek	29, 25N-103W	9,250	SGC	1954	RMSWSA

County	Company	Lease	Location		Survey Depth	Shot by	Date	Sponsored by
Weld	Sharples Oil Co.	No. 1 Ehrlick		4, 4N-64W	8,010	Petty	1954	Shell
Weld	Rogers	No. 1 M. McFarline	C NE NW	4, 8N-65W	9,817	SSC	1954	RMSWSA
Weld	Sherrod-Apperson	No. 8 Gillette	C NW NW	9, 9N-61W	9,660	Continental	1953	RMSWSA
Weld	California	No. 1 Uprr		31, 8N-66W	8,958	Midwestern	1953	Calco
Weld	Conoco	No. 1 Percy Perry		13, 9N-61W	7,552	Conoco	1953	Conoco
Weld	Lee Armer	No. 1 Warren Livestock		5, 11N-66W	11,059	Pet. Geoph.	1954	The Chicago Corp.
Yuma	Lion	No 1 Chrismer		2, 2N-48W	?	?	?	Lion
			STATE OF FLORIDA					
Charlotte	Gulf	No. 1 Vanderbilt		35, 41S-21E	12,600	Gulf	1954	Gulf
Collier	Humble	No. 3 Lee Cypress		28, 47S-29E	11,940	Humble	1947	Humble
Franklin	Humble	No. 1 A. S. Mitchell		21, 6S- 5W	4,735	Humble	1953	Humble
Hendry	Commonwealth	No. 3 Red Cattle Company		25, 45S-28E	11,667	Humble	1954	Humble
Holmes	Cashion-Stanley-Davis	No. 1 Russell		32, 5N-16W	4,192	Humble	1954	Humble
Lee	Humble	No. 1 Kirchoff		23, 45S-24E	11,724	Humble	1953	Humble
Monroe	Sinclair	No. 1 H. R. Williams		24, 59S-40E	11,940	Petty	1953	Sinclair
Okaloosa	California	No. 1 Blackman		28, 5N-24W	5,774	WGC	1953	Calco
Santa Rosa	Sunnyland Contracting Co.	No. 3 Santa Maria Unit	C SW NW	18, 5N-26W	6,471	WGC	1954	Calco
Santa Rosa	IP & Fred LaRue	No. 1 Elliott	C NE SW SW	25, 3N-24W	6,581	WGC	1954	Calco
Santa Rosa	California	No. 1 Santa Maria		33, 6N-26W	6,043	WGC	1953	Calco
Santa Rosa	California	No. 1 Berta dale		4, 4N-27W	6,367	WGC	1953	Calco
Santa Rosa	Appleman & Clinch	No. 1 USA-State of Florida		1, 3N-27W	6,509	WGC	1953	Calco
Santa Rosa	La Rue	No. 1 Elliott		25, 3N-27W	6,581	WGC	1954	Calco
			STATE OF ILLINOIS					
Bond	Texaco	No. 1 M. Andrews		2, 4N- 3W	3,290	Texaco	1953	Texaco
			STATE OF IOWA					
Dallas	Northern Natural	No. 1 Nelson		12, 79N-29W	2,838	National	1954	No. Natural
			STATE OF KANSAS					
Barber	Barber Oil Co.	No. 1 Brach		17, 34S-15W	5,540	National	1954	Chicago Corp.
Barber	Conoco & City Products	No. 1 Sternberger		5, 35S-13W	5,584	Conoco	1955	OKWSA
Ellis	Pam Kar	No. 1 Moore		32, 12S-19W	3,743	Western	1955	Stanolind
Finney	Conoco	No. 1 Kleysteuber		29, 26S-31W	5,662	Conoco	1953	Conoco
Harper	Texaco	No. 1 Baker		24, 34S- 5W	5,091	Texaco	1952	Texaco
Harper	Texaco	No. 1 Harrison		13, 33S- 6W	?	Texaco	1955	Texaco
Harper	Gulf	No. 1 Rife		31, 33S- 6W	5,133	Conoco	1954	Conoco
Kingman	Texaco	No. 1 Callison		31, 29S- 5W	4,561	Texaco	1954	Texaco
Sherman	Kingwood-Aurora	No. 1 Rauckman		11, 8S-40W	5,565	National	1952	Kingwood
Trego	Stanolind	No. 1 F. B. Rinker	SE NE NW	6, 12S-22W	4,171	WGC	1954	Stanolind
			STATE OF LOUISIANA					
Acadia	Sunray	No. 1 Pierre Cormier, Fr.		15, 11S- 1E	10,850	NGC	1952	Sunray
Acadia	Lampson, Bennet & Cole	No. 1 Hebert		6, 9S- 1W	12,700	Berg Geoph.	1953	Sun
Claiborne	Stanolind	No. 1 Luta P. Ward		26, 23N- 6W	10,230	Stanolind	1955	Stanolind
Cameron	Magnolia-Pure	No. C-1 Sweet Lake		31, 12S- 7W	8,200	Magnolia	1953	Mag. & Pure
Concordia	Magnolia	No. 2 Harris		9, 6N- 9E	7,805	Geo. Assoc.	1954	Magnolia
East Feliciana	Texaco	No. 1 Appleby		40, 4S- 1E	10,507	Texaco	1952	Texaco
Evangeline	Conoco	No. 4 Folanie Tate		44, 3S- 2E	13,010	SSC	1954	Conoco
Iberville	Shell	No. 1 Baist Cooperage & Lbr. Co.		13, 10S-11E	11,350	Shell	1953	SSWSA
Orleans	Texaco	No. 1 Point Aux Herbes	In Lake Pontchartrain		10,917	Texaco	1952	Texaco
Ouachita	Mola Gas & Feazel	No. 1 T. C. Clanton	NE SW	1, 18N- 2E	?	?	?	?
St. Landry	Stanolind	No. 1 St. Landry School Board		16, 6S- 6E	13,642	Gen. GC	1953	SSWSA
St. Mary	Shell	No. 1 State Lease 2296	In Grand Lake	44, 13S- 9E	13,000	Shell	1954	SSWSA

County	*Company*	*Lease*	*Location*		*Survey Depth*	*Shot by*	*Date*	*Sponsored by*
St. Mary	Union Oil Co.	No. 1 Citrus Land Co.		2, 18S -11E	11,500	Union	1954	Union Oil
St. Tammany	Sun	No. 1 Pointevent-Favre Lbr. Co.		10, 8S -15E	11,000	Sun	1954	SSWSA
Terrebonne	Shell-Pan American	No. 1 South Coast Corp.		28, 18S -18E	14,000	Shell	1954	SSWSA
Vermillion	Union Oil Co.	No. 1 Jonas L. Weill		54, 13S - 3E	12,102	Union	1953	Union Oi
			STATE OF MISSISSIPPI					
Attala	Conoco	No. 1 Suddeth		28, 13N- 6E	8,015	Conoco	1952	Conoco
Calhoun	Honolulu	No. 2 Davis		27, 12S - 1E	8,371	SSC	1954	Honolulu
Calhoun	Carter	No. 1 Crane		31, 13S - 1E	9,230	Shell	1954	Shell
George	Temple & Crow Drlg.	No. 1 Dantzler et al.		10, 2S - 9W	8,404	GGC	1952	Phillips
Hinds	Dick Quin	No. 1 Mashburn Gaddis		7, 6N- 2W	11,000	Atlantic	1954	Atlantic
Hinds	Sun	No. 1 Lancaster Gaddis Unit (cont. Vel. Log)		30, 6N- 2W	10,817	SSC	1954	Sun
Jefferson	Austral	No. 1 Phillips		9, 10N- 2W	9,271	Atlantic	1953	Atlantic
Lincoln	Lion	No. 1 Crawford		23, 7N- 9E	?	?	?	Lion
Monroe	Magnolia	No. 1-A Snow		27, 13S - 7E	4,685	SEI	1953	Magnolia
Rankin	Lion	No. 2 Denkman		22, 7N- 4E	?	?	?	Lion
Monroe	Brooks	No. 1 Benefiel		32, 15S -18W	5,870	Atlantic	1953	Atlantic
			STATE OF MONTANA					
Blaine	Tide Water	No. 1 Sam Unruh		32, 36N-19E	4,264	SSC	1954	Tide Water
Blaine	Tide Water	No. 1 Munsen-Torvik		8, 37N-21E	4,945	SSC	1955	Tide Water
Daniels	Socony-Vacuum	No. F-11-6-P Police Creek		6, 33N-47E	9,800	Socony	1954	Socony
Daniels	Carter	No. 1 Danielson		12, 36N-47E	7,400	Carter	1953	Carter
Dawson	Stanolind	No. 1 Northern Pacific "E"	C NE SE	21, 20N-52E	11,387	Stanolind	1954	RMSWSA
Dawson	Texaco	No. 1 Hoffer		10, 15N-54E	9,765	Texaco	1953	Texaco
Dawson	Texaco	No. 1 NP "G" NCT-7		19, 14N-55E	10,795	Texaco	1952	Texaco
Dawson	Shell	No. 14-5B N. P.		5, 22N-50E	9,640	Shell	1953	Shell
Dawson	Shell	No. 21-15 N. P.		15, 13N-56E	9,890	Shell	1954	Shell
Dawson	Shell	No. 22-9 Knudson		9, 23N-50E	7,744	Shell	1953	Shell
Fallon	Stanolind	No. 1 Northern Pacific "D"	C SW SE	21, 4N-60E	9,792	WGC	1953	RMSWSA
Fallon	California	No. 1 Pennel		15, 10N-56E	10,650	United	1954	Calco
Fallon	F. R. Anderson-Bohle	No. 41-20		20, 7N-57E	5,750	California	1953	RMSWSA
Fallon	Stanolind	No. 1 NPC	C NE NW	15, 9N-58E	11,500	U. Geoph.	1953	RMSWSA
Fergus	Cities Service	No. 1 Huffine		27, 17N-15E	5,916	Cities Serv.	1953	Cities Service
Garfield	California	No. 1 Peterson		13, 15N-30E	7,720	United	1954	RMSWSA
Garfield	Murphy	No. 1 NPRR	NW NE	23, 15N-34E	6,114	United	1953	Sohio
Garfield	Shell	No. 14-34 Skunk-Williamson		34, 16N-42E	9,355	Shell	1954	Shell
Glacier	Union Oil Co.	No. 355 Tribal Well No. 18 Montana Power Co.		10, 37N- 7W	3,053	Union	1953	Union
Hill	General Petr. Corp.	No. 36-12-P Erickson		12, 36N-15E	6,304	Petty	1952	Gen. Pet. Corp.
Hill	General Petr. Corp.	No. 36-12-P Mud Lake	3930S & 3630W NW		6,300	Gen. Pet.	1954	RMSWSA
Hill	Seaboard-Union	No. 1 Dolezal	C SW SW	21, 35N-10E	5,416	Seaboard	1953	RMSWSA
McCone	Stanolind-Amerada	No. 1 Northern Pacific	C SE SE	5, 20N-45E	9,303	WGC	1953	RMSWSA
McCone	Shell	No. 32-33 B		33, 22N-48E	11,075	Rayflex	1953	Shell
McCone	Socony	No. 1 Waller F-11-20-P		20, 21N-40E	9,821	Socony	1954	Socony
McCone	Hodge	No. 1 Eggebracht		3, 23N-40E	12,000	Union	1953	RMSWSA
McCone	Shell	No. 22-25 BNP		25, 22N-48E	10,195	Shell	1953	Shell
Phillips	U. S. Government	No. 1 South Zortman		20, 23N-26E	6,479	Conoco	1952	Conoco
Prairie	Phillips-Amerada	NPRR		33, 12N-53E	11,500	Shell	1954	RMSWSA
Prairie	Shell	No. 32-11 BNP Pine Unit		11, 12N-50E	9,148	Shell	1953	Shell
Richland	Sun	No. 1 Beagle		17, 23N-59E	12,877	Sun	1954	Sun
Richland	Eramont et al.	No. 1 NPRR		21, 23N-54E	11,500	Shell	1954	RMSWSA
Richland	Shell	Etzell No. 22-29		29, 26N-51E	10,127	Shell	1953	Shell
Roosevelt	Deep Rock	No. 1 Le Page		14, 28N-59E	9,546	Texaco	1955	Texaco

County	Company	Lease	Location	Survey Depth	Shot by	Date	Sponsored by
Roosevelt	Delhi	No. 1 Danielson	5, 27N-51E	6,507	SSC	1953	RMSWSA
Roosevelt	St. Joseph Lead-Conoco	No. 2 Fast	14, 30N-46E	6,576	Conoco	1953	Conoco
Rosebud	Cosden Exploration	No. 1 Nefsy-Thompson	34, 11N-42E	8,854	Rayflex	1953	Shell
Sheridan	Zack Brooks Drlg. Co.	No. 1 Larsen	2, 32N-55E	8,510	Union	1954	Union
Teton	General Petr.	No. 1 Blackleaf	14, 26N- 9W	7,344	Socony	1954	Socony
Valley	California	No. 1 Content	33, 26N-34E	6,751	WGC	1953	Calco
Wilbaux	Shell	No. 23-20 NP	20, 12N-57E	9,152	Shell	1953	Shell
Yellowstone	Cities Service	No. 1 Cleveland	11, 4N-25E	8,066	Cities Serv.	1953	Cities Service
		STATE OF NEBRASKA					
Buffalo	Jones-Shelburne & Farmer	No. 1 Urwiller	8, 11N-13W	3,556	Conoco	1955	Conoco
Cheyenne	The Chicago Corp.	No. 1 Taylor-Ladegard	20, 13N-49W	5,325	Pet. Geoph.	1952	The Chicago Corp.
Phelps	Pure	No. 1 Kline NW NE SW	13, 6N-18W	4,319	WGC	1953	Pure
		STATE OF NEW MEXICO					
Chaves	Stanolind	No. 1 Polecat Canyon Unit	34, 10S-31E	11,750	Western	1952	?
Chaves	West Coast Hydro Carbon	No. 1 Hopp	28, 15S-28E	10,158	?	1952	Stanolind
Chaves	Hassie Hunt	No. 1-C State	16, 11S-31E	11,668	Southern	1952	SOT
Chaves	Kerr-McGee	No. 1-A State	32, 13S-29E	10,530	United	1953	Honolulu
Chaves	Magnolia	No. 1 Shaw-Federal	6, 13S-31E	11,540	Magnolia	1953	Magnolia
Chaves	Lion	No. 1 Haire	12, 6S-30E	9,020	Tomlinson	1954	Lion
Chaves	West Coast Hydro Carbon	No. 1 Black Hill Unit	28, 17S-20E	5,610	Empire	1953	Stanolind
Chaves	Blackford	No. 1 Roberts	10, 15S-26E	8,437	General	1954	Superior
Colfax	Conoco	No. 1 St. Louis Rocky Mtn. & Pacific	13, 30N-22E	5,165	Conoco	1954	Conoco
Eddy	Conoco	No. 1 East Texas Hill	1, 22S-21E	10,588	Conoco	1953	Conoco
Eddy	Stanolind	No. 1 Lakewood Unit	34, 19S-25E	10,486	?	1953	Stanolind
Eddy	Gulf	No. 1 Federal Gen. American	24, 17S-29E	13,174	GR & DC	1953	GR&DC
Eddy	Richardson & Bass	Federal-Cobb	23, 20S-31E	10,430	Barnes Exp.	1953	R&B
Eddy	Richardson & Bass	Federal-Fidel	27, 21S-20E	15,319	Unger Exp.	1953	E. E. Unger
Eddy	Richardson & Bass	Federal-Harrison	12, 25S-30E	10,000	Barnes Exp.		A. L. Barnes
Eddy	Stanolind	No. 1 State AB	29, 17S-28E	?	?	1953	Stanolind
Eddy	Stanolind	No. 1 Guadalupe Foothills Unit	20, 22S-25E	11,324	Empire	1953	Stanolind
Eddy	Stanolind	No. 1 State "AD"	Sc. 10, 19S-28E	13,240	Empire	1954	Stanolind
Eddy	Kelly	No. 1 McMillan	Sc. 36, 20S-26E	11,551	Empire	1954	Stanolind
Lea	Texas Pac. Coal & Oil Co.	No. 1 Lane Mill Unit	32, 15S-32E	13,583	Petty	1953	Mid-Continent
Lea	J. Don Hudgens	No. 1 Webb	20, 15S-37E	13,500	Texaco	1954	Texaco
Lea	Texaco	No. 2 State "AT"	10, 14S-33E	13,647	Texaco	1954	Texaco
Lea	Stanolind	No. 1 State "X"	11, 17S-36E	11,487	?	1952	Stanolind
Lea	Conoco	No. D-2 Anderson Ranch Unit	11, 16S-32E	13,690	Conoco	1953	Conoco
Lea	Conoco	No. 1 Wilder	20, 26S-32E	4,621	Conoco	1954	Conoco
Lea	Conoco	No. 1 Sanderson B-9	9, 20S-36E	10,585	United	1955	NMFU
Lea	Conoco	No. 1 B-28 Burger	28, 20S-38E	9,378	Stanolind	1952	Stanolind
Lea	Snowden	No. 1 Santa Fe	27, 11S-36E	13,269	Stanolind	1953	Stanolind
Lea	Shell	No. 1 RA State	31, 18S-36E	12,348	Midland	1952	Shell
Lea	Shell	No. 1-CA State	23, 16S-36E	12,640	Midland	1952	Shell
Lea	Gulf	No. 1 Lea State "AN"	27, 13S-33E	13,372	GR&DC	1952	GR&DC
Lea	Gulf	No. 1 Lea State "AT"	21, 14S-32E	13,420	GR&DC	1952	GR&DC
Lea	Sinclair	No. 4 Whitman	26, 14S-37E	12,642	?	?	Sinclair
Lea	TPC&O	No. 1 Dry Lake	33, 13S-32E	12,663	Empire	1953	TPC&O
Lea	Wilshire	Harbison	8, 14S-37E	11,613	General	1953	Wilshire
Lea	Humble	No. 1 "AC" State	22, 17S-35E	13,865	United	1953	SSWSA
Lea	Western Natural	No. 1 Eidson	35, 16S-35E	12,740	Midland	1953	Shell
Lea	Pure	No. 1-B State Lea	10, 16S-35E	13,025	Empire	1953	Pure
Lea	Honolulu	Tillie Lewis	14, 13S-38E	12,200	United	1953	Honolulu

County	*Company*	*Lease*	*Location*	*Survey Depth*	*Shot by*	*Date*	*Sponsored by*
Lea	Forest & Houston	No. 1 State	26, 13S-37E	12,400	Empire	1953	Forest
Lea	Buffalo	No. 12-B Baish	22, 17S-32E	13,540	Southern	1952	Buffalo
Lea	Gulf	No. 12-B D. H. Leonard "A"	33, 24S-38E	7,900	Gulf	1953	Gulf
Lea	Sun	No. 1 H. E. Harper	26, 25S-35E	14,819	Stanolind	1953	Stanolind
Lea	Stanolind	No. 3 State "Y"	32, 24S-38E	8,097	Stanolind	1953	Stanolind
Lea	Stanolind	No. 1 State "AC"	31, 16S-36E	13,010	?	1953	Stanolind
Lea	Atlantic	No. 1 "AD" State	2, 9S-36E	9,755	Atlantic	1954	Atlantic
Lea	Superior	No. 1-23 McAlpin	23, 18S-35E	12,340	SSC	1954	Suuperior
Lea	British-American	No. 1 Fields	12, 24S-35E	8,680	United	1954	British-Am.
Lea	Texas Pac. Coal & Gas	No. 1 South Cross Roads Unit	10, 10S-36E	12,427	SSC	1954	TP&CG
Lea	Hall	No. 1-A State	Sc. 16, 15S-36E	13,569	Mid. Geoph.	1954	Shell
Lea	Shell	No. 1 Spencer Unit	Sc. 25	10,375	Mid. Geoph.	1954	Shell
Lea	Argo	No. 1 Tomlinson	Sc. 14, 15S-38E	12,868	Empire	1954	Stanolind
Lea	Warren	No. 1 Cox	Sc. 14, 14S-38E	13,375	General	1954	Superior
Lea	Ashman & Hilliard	No. 1 State Brazos Unit	Sc. 5, 14S-32E	10,026	Gulf	1953	Gulf
Lea	Jake Hamon	No. 1 Federal-Davis	Sc. 13, 17S-38E	12,150	Empire	1954	Gulf
Lea	Geo. P. Livermore	No. 1 Tyson Fields	Sc. 35, 12S-38E	12,245	Empire	1954	Gulf
Rio Arriba	South Union	No. 1-A Jicarillo	23, 26N-4W	?	?	1953	Stanolind
Rio Arriba	Superior	No. 1-7 Sealy Government	Sc. 7, 25N-6W	8,146	Western	1954	Stanolind
Sandoval	Magnolia-Federal	No. 1 Hutchinson	14, 19N-3W	9,684	Stanolind	1953	Stan. & Mag.
San Juan	Stanolind	No. 13 USG	19, 10S-29E	7,456	Stanolind	1952	Stanolind
San Juan	South Union	No. 2-A Tex-Mavajo	35, 32N-18W	?	?	1953	Stanolind
San Juan	Conoco	No. 1 South Ute	26, 32N-20W	8,009	Concoo	1954	Conoco
San Juan	Honolulu	No. 1 Navajo	6, 31N-17W	8,673	Century	1953	Honolulu
San Juan	Stanolind	No. 1 Navajo Tribal	(Vel. log. only) 12, 29N-17W	6,383	SSC	1954	Stanolind
Valencia	Humble	No. 1 Santa Fe Pacific	18, 6N-1W	10,860	Humble	1953	Humble

STATE OF NORTH DAKOTA

Billings	Northwestern Improvement	No. 1 NPRR	17, 143N-100W	13,800	Stanolind	1954	RMSWSA
Bottineau	Lion Oil Co.	No. 1 Huss	23, 163N-75W	6,345	Petty	1953	Lion
Bottineau	Lion Oil Co.	No. 1 Erickson	32, 164N-78W	5,837	Tomlinson	1953	Lion
Bowman	Hunt	No. 1 State	16, 120N-104W	9,905	Socony	1954	Socony
Dunn	Socony	No. F-42-6-P Dvorak	6, 141N-94W	12,556	Socony	1954	Socony
Foster	Socony	No. 1 Jim Carr	23, 146N-66W	3,556	Socony	1954	Socony
Golden Valley	Blackwood & Nickols	No. 1 Gilman Lang	15, 140N-105W	12,500	Stanolind	1954	RMSWSA
Golden Valley	Gulf NP	No. 1 Bundy-Federal	3, 143N-103W	9,228	Gulf	1954	Gulf
Golden Valley	Gulf NP	No. 1 Dorough Federal	24, 143N-103W	13,300	Gulf	1954	Gulf
Grant	Youngblood & Youngblood	No. 1 Kelstrom	26, 133N-83W	6,750	Petty	1953	Shell
Hettinger	Socony	No. F-14-24-P Jacobs	24, 134N-96W	10,410	Socony	1954	Socony
Logan	Hunt	No. 1 Fuller	6, 136N-73W	5,090	UGC	1954	Atlantic
McIntosh	Calvert Exploration	No. 1 John Bender	19, 130N-69W	3,673	Socony	1954	Socony
McKenzie	Texaco	No. 1 Gov't. Dorough	8, 153N-98W	8,938	Texaco	1953	Texaco
McKenzie	California	No. 1 Rough Creek	13, 148N-98W	12,000	United	1954	RMSWSA
McKenzie	Phillips-Gulf-Skelly	No. 1 Hoehn	13, 152N-102W	13,820	UGC	1954	Phillips
McKenzie	Stanolind	No. 1 Woodrow Star	21, 152N-94W	12,000	Stanolind	1953	RMSWSA
Mountrail	Hunt	No. 1 Anderson	25, 157N-89W	10,400	Hunt	1954	RMSWSA
Mountrail	Amerada	No. 1 Clifford Rice	25, 158N-94W	8,500	Stanolind	1953	RMSWSA
Mountrail	OWR Oil Co. & Whitson	No. 1 Nels Johnsberg	15, 158N-93W	8,535	Stanolind	1953	Stanolind
Renville	Calvert-Ward	No. 1 State "A" SW SW	36, 164N-87W	5,400	United	1954	Sohio
Renville	Sohio	No. 1 Marcil NW NW	13, 163N-84W	4,570	Nance	1955	RMSWSA
Rolette	Lion Oil Co.	No. 1 Sebelius	23, 161N-73W	5,500	Petty	1952	Lion
Stark	Hunt	No. 1 Victor H. Kudrna	20, 139N-97W	10,500	UGC	1954	Atlantic
Stutsman	General Atlas	No. 1 Peplinski	21, 142N-63W	2,915	National	1952	Atlnatic
Stutsman	Butterfield	No. 1 Trautman	5, 139N-68W	4,300	Atlantic	1954	Atlantic

County	*Company*	*Lease*	*Location*	*Survey Depth*	*Shot by*	*Date*	*Sponsored by*
Stutsman	Calvert	No. 1 Wood	24, 139N- 67W	3,700	Atlantic	1954	Atlantic
Stutsman	Calvert	No. 1 M. Myers	25, 137N- 67W	3,694	Atlantic	1954	Atlantic
Tower	Union of California	No. 1 Saari	35, 161N- 68W	4,405	National	1952	Union of Calif.
Ward	Quintana Petr. Corp.	No. 1 Chris W. Linnertz	33, 156N- 83W	8,925	Petty	1952	Quintana Pet. Corp.
Ward	Stanolind	No. 1 Waswick	C SW NE 2, 153N- 85W	10,900	WGC	1952	RMSWSA
Ward	Harrison	No. 1 Anderson	21, 157N- 85W	8,090	NGC	1953	Calco
Williams	Hunt	No. 1 Weyrauch	27, 156N- 97W	9,330	UGC	1954	Atlantic
			STATE OF NEVADA				
Elko	Gulf	No. 1 Wilkins Ranch	21, 38N-61E	8,396	Gulf	1954	Gulf
Elko	Gulf	No. 1 Pete Itcaina	3, 37N-50E	5,400	Gulf	1954	Gulf
Elko	Gulf	No. 1 Thousand Springs	8, 40N-66E	8,360	Gulf	1954	Gulf
			STATE OF OKLAHOMA				
Alfalfa	Conoco	No. 1 Estella Hill	23, 29N-11W	5,553	Conoco	1955	Conoco
Beaver	Texaco	No. 1 Barby	2, 4N-25E	6,850	Texaco	1954	Texaco
Beaver	Sinclair	No. 1 Maple	26, 5N-24E	6,548			Sinclair
Beaver	Sinclair	No. 1 Barby	21, 4N-26E	9,545			Sinclair
Beaver	Sinclair	No. 1 Alexander	28, 2N-27E	8,173	?	1954	Sinclair
Beaver	Sinclair	No. 1 Knight	22, 3N-23E	7,474	?	1954	Sinclair
Bryan	Stanolind	No. 1 Quinton Little	5, 6S - 8E	7,603	SSC	1954	Stanolind
Carter	Sunray	No. 1 Fitzgerald	12, 3S - 1W	10,465	OGC	1955	Sunray
Carter	Carter	No. 3 C. R. Smith	19, 3S - 1E	12,150	Rayflex	1954	Seaboard
Cleveland	Conoco	No. 1 Brendle	15, 8N- 1W	7,210	Conoco	1954	Conoco
Coal	Texaco	No. 1 Hodges	6, 1S -10E	7,681	Texaco	1953	Texaco
Coal	Pasotex	No. 1 Underhill	26, 1N-11E	15,657	Western	1954	SOT
Coal	W. R. Whittaker	No. 1 Mowdy	10, 2N-11E	12,500	Okla. Seis. Co.	1954	Magnolia
Comanche	Stanolind	No. 1 Daisy Perdaofpy	11, 4N-12W	9,660	SSC	1954	Stanolind
Custer	Parker Drilling Co.	No. 1 Miller	22, 15N-16W	11,953	Conoco	1952	Conoco
Ellis	Conoco	No. 1 Berryman	15, 17N-23W	13,290	Conoco	1953	Conoco
Grady	Jordan	No. 1 F. C. Hall	SW NE 8, 8N- 6W	13,828	SSC	1954	OKWSA
Garvin	Vickers	No. 1 Sunray-Crawford	C NE NW 31, 3N- 3W	10,023	OGC	1955	Sunray
Garvin	Conoco	No. 4 Rose Vose 5	5, 2N- 3W	9,629	Conoco	1954	Conoco
Grant	Conoco	No. 1 Connery	32, 28N- 8W	6,150	Conoco	1954	Conoco
Hughes	Fleet Drilling	No. 1 Patterson	21, 5N-11E	7,788	SSC	1954	Stanolind
Logan	O'Rourke-Sunray	No. 1 Campbell	30, 17N- 1E	5,350	Amerada	1953	Amerada
Love	Texaco	No. 1 Dolly Wallace	1, 8S - 2W	5,880	Texaco	1952	Texaco
McClain	Kenneth A. Ellison	No. 1 Cleveland	C NE NW 2, 8N- 4W	9,710	SSC	1954	SSC
Pittsburg	Magnolia	No. 1 Manschreck	28, 6N-17E	12,900	Okla. Seis. Co.	1954	Magnolia
Pittsburg	Signal	No. 1 Hoehman	16, 12E- 2N	6,889	Intl. Geoph.	1954	Signal
Pottawatomie	Sunray	No. 1 Guffenstein	NW NW NW 22, 8N- 2E	5,874	OGC	1952	Sunray
Pottawatomie	Amerada	No. 1 Lempges	3, 11N- 2E	5,858	GRC	1953	Amerada
Pottawatomie	Russell Cobb, Jr.	No. 1 E. E. Mullins	15, 6N- 2E	5,518	Conoco	1955	Conoco
Texas	Texaco	No. 1 Cook	27, 1N-10E	7,304	Texaco	1953	Texaco
Tillman	Sunray Oil Corp.	No. 4 Alexander	3, 3S -19W	5,036	Okla. Geop. Co.	1952	Sunray
Woods	Phillips	No. 1 Sandra "A"	8, 26N-15W	7,527	SSC	1954	Phillips
			STATE OF TEXAS				
Anderson	Tide Water	No. 1-D H. R. Rampy	James Wilson Surv. A-793	13,050	Petty	1954	SSWSA
Anderson	?	No. 1 Signal & Concho Carnes	1518' WL., 660' NL, L.Z. & Harold Tract	6,913	GSI	1954	Signal-Concho
Andrews	Texaco-Mabee	No. 1 J. E. Mabee	Sec. 32, Blk. 39, T 3N, G&MMBA	13,380	Texaco	1953	Texaco
Andrews	Texaco	No. 1 Mabee "B"	Sec. 10, Blk. 40, T&PRR	13,091	Texaco	1954	Texaco
Andrews	T. P. & Seaboard	No. 1-C Midland Farms	Sec. 8, Blk. 41, T 1N	4,898	Texas	1941	Texas

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Andrews	Anderson Pritchard	No. 1-24 Fasken	Sec. 24, Blk. 42, G&MMB&A	12,749	Stanolind	1952	Stanolind
Andrews	Ralph Lowe	No. 1-K Fasken	Sec. 43, Blk. 41, TWP&N	13,029	?	1952	Stanolind
Andrews	Fuhrman Petr.	No. 1-E Ford	Sec. 16, Blk. A-43, PSL	12,374	?	1953	Stanolind
Andrews	Shell	No. 1-A-1 University	Sec. 16, Blk. 1, Univ. Lands	12,545	Portable	1952	Shell
Andrews	Texas	No. 1-AB State	Sec. 22, Blk. 5, Univ. Lands	12,645	Texas	1952	Texas
Andrews	Atlantic	No. 4 University "X"	Sec. 17, Blk. 12, Univ. Lands	10,890	Atlantic	1953	Atlantic
Andrews	Magnolia	No. 1 BA Fasken	Sec. 21, Blk. 40, T 2N, T&P	13,500	Magnolia	1953	Magnolia
Andrews	Sharples	No. 1-A Means	Sec. 16, Blk. 3, PSL	12,780	Atlantic	1953	Atlantic
Andrews	Wilshire	No. 1 Cox	Sec. 16, Blk. A-33, PSL	10,200	Southern	1953	Wilshire
Andrews	APOC	No. 8 Cowden	Sec. 102, W. F. Cowden Strip	12,260	?	1953	Gulf
Andrews	CSO	No. 1 University "AT"	Sec. 26, Blk. 10, University	12,694	Empire	1953	CSO
Andrews	Forest & Monterey	No. 1-C University	Sec. 20, Blk. 4, University	13,904	Dawson	1954	Forest
Andrews	TPC&O Co.	No. 1 University "K"	Sec. 46, Blk. 9, University	5,825	Empire	1953	Gulf
Andrews	Gulf	No. 1-E State "AM"	Sec. 16, Blk. 9, University	12,900	Empire	1953	Gulf
Andrews	Anderson-Pritchard	No. 8 Cowden	Sec. 102, W. F. Cowden Survey	12,260	Gulf	1953	Gulf
Andrews	Gulf	No. 1-E State "BL"	Sec. 20, Blk. 9, University	12,550	Gulf	1953	Gulf
Andrews	Glasco, Fryer & Hanson-Roden, Darden & McRae	No. 1 L. L. Butler	Sec. 14, Blk. A-19, PSL	12,543	Empire	1953	Gulf
Andrews	Stanolind Farms	No. 1 AE Midland	Sec. 15, Blk. 41, T 2N, G&MMB&A	12,955	?	1953	Stanolind
Andrews	Atlantic	No. 19-B University	Sec. 13, Blk. 9, University	8,508	Atlantic	1954	Atlantic
Andrews	Conoco	No. 1-8 University	Sec. 8, Blk. 7, University Lands	13,845	Conoco	1952	Conoco
Andrews	Conoco	No. 6 McCullum-Weibusch	Sec. 24, Blk. A-44, PSL	13,410	Conoco	1954	Conoco
Andrews	Conoco	No. 6-17-1 University	Sec. 17, Blk. 6	12,636	Conoco	1954	Conoco
Andrews	Ralph Lowe	No. 1 Deep Rock	Sec. 5, Blk. A-46, PSL	11,255	Atlantic	1954	Atlantic
Andrews	Atlantic	No. 1 University 9-C	Sec. 14, University Blk. 9	12,685	United	1954	Atlantic
Andrews	Hunt	No. 1 J. M. White	Sec. 13, Blk. A-34, BSL	13,500	Gulf	1954	Gulf
Andrews	Honolulu	No. 2-D Parker	Sec. 30, Blk. A-44, PSL	10,975	United	1954	Honolulu
Andrews	Sinclair	No. 1 Cobb	Sec. 16, Blk. A-46, PSL	?	?	1954	Sinclair
Andrews	Sinclair	No. 1 Ford	Sec. 21, Blk. A-43, PSL	?	?	1954	Sinclair
Andrews	Richardson & Bass	No. 1 R. McWhorter	Sec. 13, Blk. A-48, PSL	11,445	Empire	1954	Gulf
Aransas	Humble	No. 1 St. Tr. 692, Gulf of Mex.	Gulf of Mex. State Tr. No. 692	14,967	Humble	1954	Humble
Armstrong	Burdell	No. 1 McGehee	Sec. 185, Blk. M-9 J. G. Gibson	8,464	Empire	1954	SOT
Bastrop	General Crude Oil Co.	No. 1 J. J. Ott	Wm. O'Connell Surv. A-272	8,200	Petty	1954	Shell
Bee	Humble	No. 1 Carpenter	R. P. Little Surv. No. 2, A-464	9,445	Humble	1954	Humble
Bexar	General Crude Oil Co.	No. 1 Rogers Ranch	J. S. Collard Surv. A-151	5,875	Petty	1954	Petty
Borden	Blanco	No. 1 W. L. Miller	746 NF&L-585 FWL, NE¼, 11, Blk. 33, 4N, T&P Survey	8,444	WGC	1953	Texas
Borden	Texaco	No. 1 Canning	211, Blk. 97, H&TCRR	6,183	Empire	1953	Texaco
Borden	Gulf	No. 1 Clayton & Johnson	Sec. 40, Blk. 31, T6N, T&P	9,550	?	1950	Gulf
Borden	Texaco	No. 1-B Clayton	Sec. 29, Blk. 32, T4N, T&P Sur.	8,136	Western	1953	Texaco
Borden	Double U	No. 1A Spinnler	Sec. 464, Blk. 97, H&TC	8,334	Portable	1953	Shell
Borden	McElroy Ranch	No. 1 Higginbotham	Sec. 16, Blk. 321, T3N, T&P	9,305	Empire	1953	Gulf
Borden	Gulf	No. 1 C. C. Cannon	Sec. 30, Blk. 33, T5N, T&P	10,500	Empire	1953	Gulf
Borden	Gulf	No. 1 J. L. Higginbotham et al.	Sec. 18, Blk. 31, T3N, T&P	8,046	Empire	1953	Gulf
Borden	Stanolind	No. 1 J. H. Beal	Sec. 14, Blk. 31, T3N	9,100	Empire	1954	Stanolind
Borden	Skelly	No. 1 Windham	Sec. 674, Blk. 97, H&TC	8,565	Empire	1954	Stanolind
Bosque	Proffitt	No. 1 J. W. Henry	Aaron B. King Survey	6,222	Humble	1953	Humble
Brazoria	Humble	No. 1 S. W. Angleton Gas Unit Well	Wm. Roberts Surv. A-124	11,403	Humble	1952	SSWSA
Brewster	Slick-Urchel	No. 1 M. Decie	Sec. 47, Blk. 4, GC&SF	9,600	Gulf	1953	Gulf
Brooks	Seaboard Oil Co.	No. 1 C. V. Villerreal et al.	La Encantada Grt., A-97	7,752	Petty	1954	Shell
Cameron	Shell	No. 1 Paul Hulsey	San Benito Land & Water Co. B246	10,600	Shell	1952	SSWSA
Cass	Coats	No. 1 Cochran	N. D. Frazier Surv. A-354	7,790	Western	1954	Stanolind
Castro	SOT	No. 1 Steakley	Sec. 25, Blk. 52, LL&RR	8,259	Western	1953	SOT
Chambers	SOT	No. 1 Jackson Est.	37 actr. F. Jackson Lse.	9,642	Southern	1953	SSWSA

County	Company	Lease	Location	Survey Depth	Shot by	Date	Sponsored by
Chambers	Sun	No. 7 Barrow	1000' FNL-1800' FEL-Elisha Stevenson A-363	10,800	Sun	1952	Sun
Cherokee	D. D. Feldman	No. 1 R. B. Johnson	C. Schneider Surv. A-813	5,075	United	1954	D. D. Feldman
Cherokee	D. D. Feldman	No. 1 Adams et al.	I. Reynolds Surv. A-728	4,840	United	1954	D. D. Feldman
Childress	Hamill	No. 1 McSpadden	Sec. 379, Blk. 4, W&NWRR	6,515	?	1953	Stanolind
Clay	Texaco	No. 1 Deason	Blk. 87, Angelina Co. Sch. Land	6,258	Texaco	1952	Texaco
Cochran	Stanolind	No. 1 Reed "C"	Sec. 19, Harrison & Brown	12,677	?	1952	Stanolind
Cochran	Texas	No. 2 Mallet "G"	Sec. 22, B-D, Gibson	12,090	?	1953	Stanolind
Cochran	McElroy Ranch	No. 1 Ausmus	Sec. 26, Hansford CSL	8,075	?	1953	Stanolind
Cochran	Stanolind	No. 1 D. C. Reed "D"	Sec. 58, 600' FS&EL, H&D Surv.	12,625	Empire	1953	Stanolind
Coke	Superior	No. 1-161 Price	Sec. 161, Blk. 2, T&TC	7,360	Superior	1953	Superior
Coke	Deep Rock	No. 1-A White	Sec. 286, Blk. 1-A, H&TC	6,582	?	1953	Stanolind
Coke	Diamond Drilling	No. 1 Featherstone	Sec. 184, Blk. 2, H&TC	6,712	?	1953	Stanolind
Coke	Lion Oil Company	No. 1 Waldrop	Sec. 369, Blk. 1-A, H&TC	6,638	Tomlinson	1950	Lion
Coke	Laan-Texas	No. 1 Reid	Sec. 7, Angel	6,796	?	1953	Stanolind
Coke	Stanolind	No. 1 Burns	Sec. 238, Blk. 2, H&TC	7,184	Empire	1954	Stanolind
Collins	Humble	No. 1 H. C. Miller	L. Searcy Survey A-828	9,673	Humble	1953	SSWSA
Cooke	Humble	No. 1 V. A. Castle	Lot 6, A. Hilburn Surv.	7,088	Texaco	1953	Texaco
Cooke	Lion Oil Co.	No. 1 Waldron	Sec. 369, B. 1-A, H&TC	6,638	Tomlinson	1950	Lion
Cooke	Ada Oil	No. 1 H. L. Settler	J. M. Culp Sur. A-1551 (C. Vel. Log)	9,317	SSC	1954	Phillips
Crane	Gulf	No. 1 Eates	Sec. 2, B. 28, PSL	7,200	Gulf	1943	Gulf
Crane	McElroy Ranch	No. 1 Darr	Sec. 7, CT&MC	5,790	GR&DC	1952	GR&DC
Crane	Gulf	No. 2-E Estes	Sec. 8, B. B-28, PSL	7,870	GR&DC	1952	GR&DC
Crane	Forest	No. 1-B University	Sec. 11, B-30-University	12,197	Dawson	1952	Forest
Crane	Humble	No. 5 Jax M. Cowden	Sec. 25, B.X., CCSD&RGNG	10,507	Humble	1953	Humble
Crane	T. M. Evans	No. 1 Jordan-Ingram-Stanolind	Sec. 12, B. 22, PSL	8,320	Empire & Gulf	1953	Gulf
Crane	Gulf-Stanolind	No. 1 State "EH"	Sec. 9, B. 30, Univ.	12,000	Empire	1953	Gulf
Crane	Gulf	No. 1 P. J. Lea	Sec. 40, B. 32, PSL	8,420	Empire	1953	Gulf
Crane	Gulf	No. 2 P. J. Lea	Sec. 30, B. 32, PSL	8,334	Gulf	1953	Gulf
Crane	Magnolia	No. 5-16 University	Sec. 16, B. 30, Univ.	12,250	Gulf	1953	Gulf
Crane	C. E. Marsh II	No. 1 P. J. Lea	Sec. 38, B. B-32, PSL	8,300	Empire	1953	Gulf
Crane	Bankline Oil Co.	No. 1 Rehmeyer	Sec. 14, B. 1, H&TC Surv.	5,890	Conoco	1954	Conoco
Crane	McElroy-Newmont	No. 7-31 Estes	Sec. 7, B. B-28, PSL	7,934	SSC	1954	SSC
Crane	T. P. Coal & Oil	No. 1 H. E. Adams Farm "A"	Sec. 8, B. B-24	11,725	Empire	1954	TP Coal & Oil
Crane	Shell	No. 1 University 30-A	Sec. 25, Univ. Blk. 30	12,148	Midland Geo.	1954	Shell
Crane	Atlantic	No. 1-36 Everitt & Glass	Sec. 36, Blk. 43, T&S, T&P	12,514	UGC	1954	Atlantic
Crane	Atlantic	No. 4 Univ. "Q"	Sec. 22, Univ. Blk. 31	8,980	UGC	1954	Atlantic
Crane	Gulf	No. 8, P. J. Lea	Sec. 30, Blk. 32, PSL	8,522	Gulf	1954	Gulf
Crane	J. J. Moran, Trustee	No. 1 R. Reed, et al.	Sec. 10, B. 4, H&TC	6,540	Empire	1954	Gulf
Crane	Gulf	No. 221 Waddell	Sec. 17, B. B-21, PSL	6,325	Empire	1954	Gulf
Crane	Gulf-Stanolind	No. 1-E State "EG"	Sec. 10, B. 30, Univ.	11,970	Gulf	1953	Gulf
Crockett	Sinclair	No. 1 Friend	Sec. 6, A-4437 Barrera Grantee	10,358	?	?	Sinclair
Crockett	Humble	No. 1 Martin	Sec. 38, B. OP, GC&SF	8,420	Humble	1952	Humble
Crockett	Sun	No. 1-A Myrtle Mitchell	Sec. 111, B. 1, I&GN	14,450	Conoco	1952	Conoco
Crockett	Sinclair	No. 1-112 University	Sec. 24, B. 7, Univ.	9,040	Sinclair	1953	Sinclair
Crockett	Conoco	No. 1 University 55-8	Sec. 8, B. 55, University	8,667	Conoco	1953	Conoco
Crockett	Conoco	No. 1 University 32-13	Sec. 13, B. 32, University	10,009	Conoco	1953	Conoco
Crockett	Conoco	No. 1-E Shannon	Sec. 15, Blk. BB, EL&RR RR	9,033	Conoco	1953	Conoco
Crockett	Conoco	No. 2-1 Powell	Sec. 2, Blk. BB-2	8,491	Conoco	1954	Conoco
Crockett	Conoco	No. 4 Harris "C"	Sec. 10, Blk. A, BS&F Surv.	9,361	Conoco	1954	Conoco
Crockett	Conoco	No. 1 University 31-36	Sec. 36, Blk. 321, Univ.	8,953	Conoco	1953	Conoco
Crockett	Conoco	No. 1 Friend	Sec. 28½, John McLelland	10,697	Conoco	1952	Conoco
Crockett	Conoco	No. 1-B Harris	Sec. 17, B. HH, GC&SF	8,776	Conoco	1952	Conoco
Crockett	Sun	No. 1A Mitchell	Sec. 3, B. 1, I&GN Surv.	14,450	Conoco	1952	Conoco
Crockett	Humble-Conoco	No. 1-V University	Sec. 10, B. 31, Univ.	9,270	Humble	1953	Humble

County	*Company*	*Lease*	*Location*	*Survey Depth*	*Shot by*	*Date*	*Sponsored by*
Crockett	Superior	No. 1-27 University	Sec. 27, B. 46, Univ.	7,355	Superior	1953	Superior
Crockett	Humble-Conoco	No. 1-U Univ.	Sec. 17, B. 46, Univ.	10,101	Humble	1953	Humble
Crockett	R. Lowe	No. 1 Neal	Sec. 6, B. 10, GC&SF	10,011	?	1953	Stanolind
Crockett	U. S. Smelt.	No. 1 Henderson	Sec. 69, B. OP, GC&SF	8,511	?	?	Stanolind
Crockett	Humble-Conoco	No. 1-X University	Sec. 7, B. 31, University	9,688	Humble	1953	Humble
Crockett	Humble	No. 1 South Gilcrease Unit	Sec. 48, B. 31, H&TC RR Surv.	7,911	Humble	1954	Humble
Crockett	Magnolia	No. 1 Shannon Hospital	Sec. 5, Blk. BB, EL&RR	7,600	Magnolia	1954	Magnolia
Crockett	Duquesne	No. 2 Shannon	Sec. 23, Blk. BB, EL&RR	9,520	Empire	1954	Superior
Crockett	Cities Service	No. 1 University "AW"	Sec. 18, B. 44, Univ. Lands	9,290	Empire	1954	CSO
Crockett	Gulf	No. 1 J. H. Tippett	Sec. 38, B. 31, H&TC	6,890	Empire	1954	Gulf
Crosby	Humble	No. 1 R. N. Irvin	Sec. 889, Blk. C-3, PSL	9,939	Humble	1953	Humble
Crosby	Stephens Petr. Co.	No. 1 Forrest	Sec. 732, Blk. B-9, EL&RR Surv.	11,420	Conoco	1951	Conoco
Culberson	Conoco	No. 1 Foster	Sec. 24, B. 88, PSL	5,261	Conoco	1952	Conoco
Culberson	Phillips	No. 1 Crews	Sec. 22, B. 59, T&P Surv.	7,600	SSC	1954	Conoco
Culberson	W. H. Hunt	No. 1 V. C. Rounsaville	Sec. 22, Blk. 108, PSL	10,402	Magnolia	1954	Magnolia
Culberson	Gulf	No. 1-C M. A. Grisham	Sec. 16, B. 60, T 5S, T&P	9,515	Gulf	1954	Gulf
Culberson	Grisham-Hunter	No. 1 M. A. Grisham-State	Sec. 19, Blk. 54, PSL	5,010	Empire	1954	Gulf
Dallam	Humble	No. 1 Belo	Sec. 1, Blk. 1, I&GN RR Surv.	6,826	Tex. Seis	1954	Humble
Dallam	Panoma	No. 1-A Hill	Sec. 10, Blk. 19, C.S.S. Surv.	6,030	Chevron	1953	SOT
Dawson	Sinclair	No. 1 Weaver	Sec. 7, B. 3, D. L. Cunningham	9,740	?	1953	Sinclair
Dawson	SOT	No. 1-4 Smith	Sec. 34, B. C-41, PSL	11,368	Southern	1952	SOT
Dawson	Cyprus Miner-Union Oil	No. 1 Goodson	Sec. 44, B. 33, T 5N, T&P	8,530	Western	1952	Texaco
Dawson	H. L. Hunt	No. 1 O. Nix	Sec. 41, B. 33, T 5N, T&P	8,465	Empire	1953	Gulf
Dickens	Natl. Assoc. Petr.	No. 1 Blackwell	Sec. 5, Blk. C, Conelee	8,388	Stanolind	1950	Stanolind
Dickens	Tri-Service	No. 1 Grantham	Sec. 234, Blk. 1, H&GN	7,478	?	1953	Stanolind
Dickens	Humble	No. F-2 Matador	Sec. 27, Blk. AS, J. S. Calloway	7,537	Humble	1952	Humble
Dimmit	Coquat & Guiberson	No. 1 H. A. Dillion	Sec. 65, Blk. 35, T&NO Surv.	11,847	Petty	1953	Shell
Ector	Texas-Gulf	No. 1 Headlee	Sec. 8, B. 41, T 2S, T&P	13,077	GR&DC	1952	GR&DC
Ector	Gulf	No. 721 Goldsmith	Sec. 4, B. 44, T 1S, T&P	10,320	GR&DC	1953	GR&DC
Ector	Sinclair-Blackwood & Nichols	No. 1-5 Neathery	Sec. 5, Blk. 41, T&P	13,261	?	?	Sinclair
Ector	Cities Service	No. 1-Q Cowden	Sec. 9, B. 43, T 2S, T&P	13,768	Empire	1953	CSO
Ector	Forest	No. 1 TXL	Sec. 31, B. 43, T 1N, T&P	11,818	Southern	1953	Forest
Ector	Gulf	No. 731 C. A. Goldsmith	Sec. 16, Blk. 44, T1S, T&P	8,733	Gulf	1953	Gulf
Ector	Tide Water	No. 1 T. McKnight	Sec. 7, Blk. 41, T2S, T&P	13,105	SEI	1953	Tide Water
Ector	Phillips	No. 1 Stockton (c. vel. log)	Sec. 17, Blk. 45, T2S, T&P	11,426	SSC	1954	Phillips
Ector	Texas	No. 1 Texas-Magnolia-Ratliff	Sec. 25, Blk. 42, T1S, T&P	13,600	Magnolia	1954	Magnolia
Edwards	Sinclair	No. 1 Miers	Menard CSL, Blk. 3	6,258	Sinclair	1953	Sinclair
Edwards	Taylor O&G	No. 1 Holman	Sec. 22, CCSD&RGNG RR	9,371	Empire	1954	Delhi-Taylor
Ellis	Mitchell	No. 1 Rush	John Chamblee Survey	3,512	Humble	1953	Humble-Shell
Fayette	Fidelity Oil & Royalty	No. 1 Roy Wagenhoff et al.	S. A. Pugh Survey, A-85	9,000	Shell	1953	Shell
Fisher	Lion	No. 1 Lanning	Sec. 10, Blk. 20, T&P	6,160	Tomlinson	?	Lion
Fisher	TPC&O Co.	No. 12-E Pardue	Sec. 199, Blk. 1, H&TC	5,950	National	1950	TP
Fisher	McLaughlin	No. 1 Flores	Sec. 312, Chumley Surv.	5,867	?	1953	Stanolind
Fisher	Woodson	No. 1 Cauble	Lot 31, League 316, El Paso SL	6,325	SSC	1954	Atlantic
Fisher	Byrd	No. 1 Davenport	Sec. 128, Blk. 3, H&TC	7,409	EVS	1954	Atlantic
Fisher	Lion	No. 1 Huddleston	Sec. 10, Blk. K, T&P	5,941	Tomlinson	?	Lion
Floyd	Sinclair	No. 1 J. M. Massie	Sec. 7, Blk. T, BS&F	9,900	Portable	1953	Shell
Franklin	Humble	No. 1 A. C. Ballard	J. L. Elder Surv. A-155	13,190	SSC	1954	SSWSA
Gaines	Rowan Drilling Co.	No. 1 Norman	Sec. 9, Blk. C-45, PSL	9,514	Texaco	1953	Texaco
Gaines	Texaco	No. 1 Tobe Foster	League 305, Dawson Co. Sch. Land	9,518	Texaco	1953	Texaco
Gaines	Texaco	No. 1-NCT-2 Tobe Foster	League 306, Dawson Co. Sch. Land	9,692	Texaco	1953	Texaco
Gaines	Texaco	No. 2 Tobe Foster NCT-1	League 305, Dawson Co. Sch. Land	12,991	Texaco	1953	Texaco
Gaines	Texaco	No. 1 Cox	Sec. 12, Blk. C-45, PSL	12,740	?	1952	Stanolind
Gaines	Sinclair	No. 1 Lee	L. 17, Lg. 284	11,545	?	?	Sinclair
Gaines	Delhi Oil	No. 1 Oil Development of Texas	Sec. 27, Blk. G, C&M RR	14,150	Atlantic	1953	Atlantic

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Gaines	Mabee	No. 1 Newton	Sec. 28, Blk. A-19, PSL	12,850	Portable	1953	Shell-Gulf-Fullerton
Gaines	Shell	No. 1 Foster	Sec. 408, Blk. G, CCSD&RGNG	11,425	Shell	1953	Shell
Gaines	Hamon	No. 1 Estes	Sec. 20, Blk. A-19, PSL	12,480	Atlantic	1953	Atlantic
Gaines	Humble	No. 1 A. Brumley	Sec. 8, Blk. A-12, PSL	11,044	Empire	1953	Stanolind
Gaines	Shell	No. 10 Pierson	Sec. 452, Blk. 6, CCSD&RGNG	11,057	Portable	1954	Shell
Gaines	Alsabrook	No. 1 Dunn (c. vel. log)	Sec. 78, Blk. H, D&WRR	13,088	SSC	1954	Phillips
Gaines	Placid	No. 1 Terry CSL (c. vel. log)	Lbr. 8, Lge. 299, CSL	14,000	SSC	1955	Phillips
Gaines	Atlantic	No. 1 Ashenhust	Sec. 132, Blk. G, WTRR	11,170	Atlantic	1954	Atlantic
Gaines	Union-Gr. West.-Murphy	No. 1 J. E. Stanley	Sec. 100, Blk. G, WTRR Surv.	12,140	WGC	1954	Atlantic
Gaines	Amerada	No. 1 Terrell CSL	Lge. 308, Terrell, CSL	13,970	GRC	1954	Amerada
Gaines	Magnolia	No. 24-D H&J Unit 1-D	Sec. 491, Blk. G, CCSD&RGNG	11,046	Magnolia	1953	Magnolia
Gaines	Felmont	No. 1 Terrell Co. Sch. Land	Lbe. 15, Lge. 309, Terrell CSL	12,770	United	1954	Felmont
Gaines	O. D. Alsabrook	No. 1 Amon G. Carter	Sec. 424, Blk. G, CCSD&RGNG	11,354	?	1954	Sinclair
Gaines	Honolulu, et al.	Wescott	Sec. 2, Blk. C-44, PSL	14,274	United	1954	Hono.-Rich. & Bass
Gaines	Hall-Stewart	No. 1 Klatenhoff	L. 3, Lg. 295, Regan CSL	12,877	Empire	1954	Gulf
Gaines	Lawton	No. 1-A Whitaker	Sec. 19, Blk. C-30, PSL	12,366	Empire	1954	Stanolind
Garza	Atlantic	No. 1 Swenson	Sec. 60, Blk. 8, H&TC	8,248	Atlantic	1954	Atlantic
Garza	Stanolind	No. 1 Shirley Bird	Sec. 82, Blk. 5, GH&H	8,530	Empire	1954	Stanolind
Glasscock	Sinclair	No. 1 Hall	Sec. 6, Blk. 34, T2S, T&P	11,073	?	?	Sinclair
Glasscock	Norsworthy	No. 1 McDowell	Sec. 29, Blk. 34, T2S	10,015	Conoco	1953	Conoco
Gray	Gulf	No. 1 E. A. Shackleton	Sec. 67, Blk. 3, I&GN	8,048	Gulf	1953	Gulf
Gray	Phillips	No. 1 Talley "A" (c. vel. log)	Sec. 118, Blk. M-2, BS&F	11,660	SSC	1955	Phillips
Gray	Phillips-Sinclair	No. 1 Jackson "C"	Sec. 208, Blk. M-2, BS&F	10,408	Sinclair	1954	Sinclair
Gray	Russell-Maguire	No. 1 Franklin	Sec. 43, Blk. A-6, H&GN	7,400	Gulf	1954	Gulf
Grayson	SOT	No. 1 Baker	800' FNL & 1000' FWL A. Harris, A-522	10,530	National	1952	SOT
Hale	Maguire	No. 1 Wheeler	Sec. 51, Blk. A-4, EL&RR	9,508	?	1953	Stanolind
Hall	J. B. Revier, et al.	No. 1 Lewis	Sec. 15, Blk. "W," Blum Surv.	6,875	?	1954	Sinclair
Hall	Sinclair	No. 1 Hughes	Sec. 81, Blk. S-5, D&P	?	?	1954	Sinclair
Hansford	Texaco	No. 1 Blakemore	Sec. 30, Blk. 4-T, T&NO	10,008	Texaco	1953	Texaco
Hansford	Humble	No. 1 Jackson	Sec. 111, Blk. 45, H&TC	9,120	Humble	1953	Humble
Hansford	Clark-Roark-Hooker & Hill	No. 1 J. A. Cavin	Sec. 3, Blk. 5-T, T&NO	6,043	Gulf	1954	Gulf
Hardeman	Magnolia	No. 1 S. E. Malone	Sec. 276, Blk. H, W&NWRR	8,724	Texas Seis.	1954	SSWSA
Hardeman	Gulf	No. 1 W. S. Dodson, et al.	Sec. 280, Blk. "A," H&TC	7,053	Gulf	1954	Gulf
Hardin	Shell	No. 1 Kirby Lumber Corp. Tr. 17-B	Ignacio Villegas Surv., A-54	9,000	Shell	1952	Shell
Hardin	Shell	No. 2 Kirby Lumber Corp. Tr. 17-B	Ignacio Villegas Surv., A-54	9,054	Shell Dev. Co.	1953	Shell
Hardin	Shell	No. 1 Kirby Lumber Corp. Tr. 152-A	H&TC RR Co. Surv. A-800	10,143	Shell	1952	Shell
Harris	Humble	No. 1-E West Fee	Sarah Deel Surv. A-13	10,583	Humble	1954	SSWSA
Harrison	LaGloria	No. 1 Cadenhead	Williams Survey	6,808	?	1952	Stanolind
Harrison	Placid	No. 1 Dunn, No. 2 Well	Newman Survey	12,000	?	1953	Stanolind
Hartley	SOT	No. 1 Guilloud	Sec. 25, Blk. LE, G&M	7,420	Empire	1954	SOT
Haskell	J. H. Snowden	No. 1 Norman	Sec. 64, Blk. 1, H&TC	6,004	Empire	1954	Stanolind
Hemphill	Sinclair	No. 1 Isaacs	Sec. 114, Blk. 41, H&TCRR	13,384	?	?	Sinclair
Hidalgo	Magnolia	No. 1 Hidalgo-Willacy Oil Co.	Las Mestendas Grant A-?	12,000	Shell	1954	SSWSA
Hockley	Standard of Texas	No. 1 Huffaker-2	1500 FWL-330 FNL, 1, Tr. 4, Blk. D	10,200	WGC	1954	Standard of Texas
Hockley	Honolulu	No. 1 Brown	L. 23, Lg. 4, Jones CSL	10,692	United	1951	Honolulu
Hockley	Sohio	No. 1 Ellwood	Sec. 5, Blk. A, PSL	11,600	United	1953	Honolulu
Hockley	Honolulu	No. 1-A Lockett	Sec. 2, Blk. 1, PSL	12,210	United	1953	Honolulu
Hockley	Great Western	No. 1 F. Burger	Tr. 8, Lg. 24, McCullough CSL	10,800	Empire	1953	Gulf
Hockley	Wm. H. Hunt	No. 1 Glimp "A"	L. 12, Lg. 700, State Capitol	9,100	Empire	1953	Gulf
Hockley	Bankline	No. 5-1 Mallet	L. 5, Lg. 34, Concho SL, A148	10,549	?	1953	Stanolind
Hockley	Hamon	No. 1 Bowman	L. 21, Lg. 720, CSL	11,440	?	1953	Stanolind
Hockley	Stanolind	No. 1 Slaughter	L. 36, Lg. 36, Zavalla CSL	11,000	?	1953	Stanolind
Hockley	Stanolind	No. 1 J. E. Armes	Sec. 54, Blk. P, C&M	11,486	?	1953	Stanolind

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Hockley	Great Western	No. 1 Copeland	L. 11, Lg. 709, Capitol	10,490	?	1953	Stanolind
Hockley	Humble	No. 1 Elwood Estate "C"	Lbr. 25, Lge. 14, Howard CSL	10,160	Humble	1954	Humble
Hockley	Honolulu	No. 18 Ellwood "A"	Sec. 13, Blk. A, R. M. Thompson	10,800	United	1954	Honolulu
Houston	Reynolds Mining Co.	No. 1 J. T. Knox	Omy Wier Survey A-93	9,500	?	1954	SSWSA
Houston	D. D. Feldman	No. 1 Paul R. Maples	B. Clark Survey, A-23	9,481	United	1954	D. D. Feldman
Howard	Stanolind	No. 1-A Barber	Sec. 45, Blk. 31, T1N, T&P	9,790	?	?	Stanolind
Howard	Stanolind	No. 1-A Snyder	Sec. 20, Blk. 30, T1S, T&P	9,182	?	1952	Stanolind
Howard	TPC&O Co.	No. 1 Tom Spencer "A"	Sec. 14, Blk. 32, T&P	9,986	Empire	1953	Joint Ownership
Howard	Stanolind	No. 1 Anderson	Sec. 3, Blk. 31, T2N, T&P	7,725	Empire	1953	Gulf
Howard	Stanolind	No. 2 Burton	Sec. 27, Blk. 33, T2N, T&P	8,908	?	1953	Stanolind
Howard	Russell Maguire	No. 1 Hyman	Sec. 59, Blk. 29, W&N RR	9,207	Conoco	1954	Conoco
Howard	Plymouth	No. 1 Oldham	Sec. 26, Blk. 27, H&TC	9,250	Empire	1954	Gulf
Howard	Stanolind	No. 1 A. Anderson	Sec. 20, Blk. 31, T2N, T&P	9,563	Empire	1954	Stanolind
Hudspeth	Magnolia	No. 1 Univ. #39881	Sec. 19, Blk. C, University	5,421	Magnolia	1953	Magnolia
Hutchinson	Amarillo Natl. Bank	No. 1 Wisdom Unit	Sec. 8, Blk. M23, TC RR	8,220	Gulf	1954	Gulf
Iron	SOT	No. 6-1 Bryant	Sec. 24, Blk. 3, H&TC	7,156	Empire	1954	SOT
Jeff Davis	Conoco	No. 1 McCutheon	Sec. 18, Blk. 11, GH&SA	9,543	Conoco	1952	Conoco
Jeff Davis	Conoco	No. 1 Rousaville	Sec. 25, Blk. 58, T9S	8,615	Conoco	1954	Conoco
Jefferson	Stanolind	No. 3-B Marrs McLean	L. Hamshire Surv. A-511	15,000	Petty	1954	SSWSA
Karnes	Seaboard	No. 1 Szalwinski	Louis Manchaca Grant A-5	11,238	Rayflex	1954	Seaboard
Kendall	Magnolia	No. 1 Ed Below	B. F. I. RR Co., Surv. 881, A-87	6,502	Magnolia	1953	Magnolia
Kenedy	Humble	No. 1 Clark & Sain	Santa Quiteria Grant A-44	12,000	Humble	1953	Humble
Kenedy	Humble	No. G-1 Kenedy	Cuatro Esquinas Pasture, A-37	10,940	Humble	1954	Humble
Kenedy	Humble	No. 4 Armstrong	La Barreta Grant, A-13	11,784	Humble	1954	Humble
Kenedy	Humble	No. 5 Armstrong	La Barreta Grant, A-13	11,955	Humble	1954	Humble
Kenedy	SOT	No. 22 St. Tr. 370	St. Tr. 370, Laguna Madre Sur.	9,777	GSI	1954	SOT
Kent	Estill & Heyser	No. 1 Lohman	Sec. 102, Blk. C, W&NW Sur.	7,322	Empire	1954	Stanolind
King	Conoco	No. 3 Alexander	Sec. 89, Blk. F, H&TC	6,495	Shell	1953	Shell
King	Conoco	No. 2 Ross	Sec. 84, Blk. 13, H&TC	6,060	Shell	1952	Shell
King	Conoco	No. 2 Alexander	Sec. 32, Blk. F, H&TC	6,155	Shell	1952	Shell
King	Shell	No. B-1 Burnett	Sec. 1, Tyler Tap	6,378	Shell	1953	Shell
King	Shell	No. A-1 Burnett	Sec. 16, Montgomery	6,688	Shell	1952	Shell
King	McAlester Fuel	No. 1 McGee	Sec. 15, Tyler Tap	6,752	Shell	1952	Shell
King	Shell	No. C-1 Burnett	Sec. 9, Blk. T, T. A. Thompson	6,262	Shell	1953	Shell
King	Shell	No. D-1 Burnett	Sec. 15, Blk. X, R. M. Thompson	6,260	Portable	1953	Shell
Kleberg	Sun	No. 1-A Dunn-Campbell	St. Tr. 979 Juan Jose Balli A-10, Padre Island	11,015	Humble	1954	Humble
Kleberg	Humble	No. 2 King Ranch Alazan	El Alazan Vicente de Ynojosa Gt. A-241	11,962	Humble	1954	Humble
Kleberg	SOT	No. 53 State 948	St. Sec. 948 Offshore	9,948	GSI	1954	SOT
Knox	Stanolind-Yeatman	No. 2 Davis	Burnett No. 3 Survey	5,934	?	1952	Stanolind
Knox	Humble	No. 1 McFadden Estate	Sec. 1, Blk. 1 Poitevent	6,211	Humble	1952	Humble
Knox	Humble	No. D-1 McFadden	Sec. 32, Blk. 13, H&TC	6,314	Texas	1953	Humble
Knox	Humble	No. S-1 Waggoner	Sec. 5, Blk. K, M. M. Thompson	6,300	Texas	1953	Humble
Lamb	Anderson-Prichard	No. 1 Gettys	Sec. 59, Blk. 1, Halsell	9,310	United	1952	Honolulu
Lamb	San Juan Exploration	No. 1 Jones	L. 16, Lg. 687, Capitol Lands	6,735	Empire	1953	GR&DC
Lamb	Texas	No. 1 Union Company	L. 12, Lg. 664	9,383	?	1953	Stanolind
La Salle	Standard of Texas	No. 1 South Texas Syndicate No. 2	Sec. 67, H&GN RR Surv.	11,500	Petty	1954	Std. of Texas
La Salle	Stanolind	No. 1 Albert M. Martin	J. M. Martin, A-1291	11,000	Petty	1954	SSWSA
Loving	Gulf	No. 1 TXL "BG"	Sec. 3, Blk. 55, T&P	4,015	GR&DC	1953	GR&DC
Loving	Magnolia	No. 1 State #39868	Sec. 4, Blk. 19, UTL	5,325	Magnolia	1953	Magnolia
Loving	Sun Oil	No. 1 J. B. Tubb	Sec. 7, Blk. C-24, PSL	12,102	Empire	1953	Gulf
Lubbock	TPCO	No. 1 Austin	Sec. 41, Blk. A, HE&WT	10,928	Empire	1954	Stanolind
Madison	Woodley Petr. Co.	No. 1 Cannon	Roy F. Fannin	10,262	National	1954	Woodley
Martin	Gulf	No. 1 Glass	Sec. 13, Blk. 30, T1N, T&P	12,870	Gulf	1950	Gulf
Martin	Stanolind	No. 1 Cowden	Sec. 30, Blk. 40, T1N, T&P	13,191	?	1952	Stanolind

County	*Company*	*Lease*	*Location*	*Survey Depth*	*Shot by*	*Date*	*Sponsored by*
Martin	Stanolind	No. 1 Flynt	L. 12, Lg. 248, Hartley CSL	13,372	?	1952	Stanolind
Martin	Phillips	No. 1-C Scharbauer	Lg. 324, La Salle CSL	13,100	Empire	1953	Gulf
Matagorda	Shell	No. 1 L. W. Kain et al.	Jas. Duncan League & Labor Sur.	6,057	Shell	1953	Shell
McLennan	Falcon Oil Corp.	No. 1 Henry Mattlage, Jr.	L. C. Woodruff	7,218	SSC	1954	Shell
McMullen	Standard of Texas	No. 1 J. B. Dilworth	Hugh Frazier Sur. No. 23A-193	12,660	Petty	1954	Std. of Texas
McMullen	Humble	No. 1 L. M. Gubbels	No. 26 (A-1350) G. H. Smith Sur.	9,737	Humble	1953	Humble
Midland	USS&R	No. 1 King	Sec. 10, Blk. 40, T1S, T&P	13,445	Sinclair	?	Sinclair
Midland	Superior	No. 1-44 Willis	Sec. 44, Blk. A, G. G. Gray	12,475	Superior	1953	Superior
Midland	Plymouth	No. 1 Midkiff	Sec. 38, Blk. 39, T4S, T&P	13,420	Atlantic	1953	Atlantic
Midland	Magnolia	No. 1 J. O. Nobles	Sec. 28, Blk. 40, T1S, T&P	13,362	Magnolia	1954	Magnolia
Midland	Warren Petr.	No. 2 TXL "G"	Sec. 39, Blk. 41, T3S, T&P	13,293	Empire	1954	Warren (SSWSA)
Midland	Cities Production-Forest	No. 1 TXL "L"	Sec. 23, Blk. 41, T3S, T&P	13,127	Dawson	1954	Forest
Midland	Forest & Cities Prod.	No. 1 Roberts "B-1"	Sec. 42, Blk. 41, T2S, T&P	12,835	Dawson	1954	Cities Service
Midland	Seaboard	No. 1 A. L. Tillman	Sec. 12, Blk. X, H. P. Hilliard	12,630	Empire	1954	Gulf
Midland	Gulf	No. 1-L Scharbauer Cattle Co.	Sec. 3, Blk. 39, T1S, T&P	13,098	Empire	1954	Gulf
Milam	Bryd Oil Corp.	No. 1 M. Blakely	A. J. Watts Survey	7,300	Shell	1953	Shell
Milam	Texas-Gulf-Sulphur	No. 1 T. G. S.	Blk. 43, Jose Leal Sur. AB-29	7,250	GSI	1955	TGS
Mitchell	Conoco	No. 1 Elwood	Sec. 41, Blk. 17, S. P. R. R. Sur.	8,418	Conoco	1954	Conoco
Morris	B. G. Byers	No. 4 P. H. Pewitt	Geo. Dyer, A-80	4,831	Sohio	1953	Sohio
Motley	Humble	No. K-1 Matador Ranch	Sec. 22, T. G. McNutt	10,586	Humble	1953	Humble
Motley	Lion	No. 1 Shoenail Ranch	Sec. 212, Blk. S-5, D&P	8,006	?	1953	Stanolind
Motley	General Crude	No. 43-1 Swenson	Sec. 43, Blk. B, John H. Stephens	4,800	National	1954	General Crude
Nolan	Stanolind	No. TXL E-1	Sec. 15, Blk. 2, T&P	6,532	Empire	1953	Stanolind
Nolan	Sun-Seaboard	No. 1 Haney	Sec. 32, Blk. X, T&P	7,402	?	?	?
Nolan	Le Bus Warner et al.	No. 1 Wimberly	Sec. 37, Blk. 5, T&P	7,003	National	1954	General Crude
Nolan	Leda	No. 1 Featherstone	Sec. 93, Blk. 22, T&P	5,280	Midland Geoph.	1954	Shell
Nolan	Sinclair	No. 1 Gulf, Colo. & Santa Fe	Sec. 30, Blk. 22, T&P	?	?	?	?
Ochiltree	Welch Oil Company	No. 1 Brillhart	Sec. 926, Blk. 43, H&TCRR	8,518	Texaco	1953	Texaco
Ochiltree	Texaco	No. 1 S. P. Daniels	Sec. 139, Blk. 4-T, T&NO	10,125	Texaco	1954	Texaco
Parker	Humble	No. 1 J. H. Doss	J. H. Gaines Sur. 262, A-1748	5,895	Humble	1953	Humble
Parmer	Gulf	No. 1 Keleihor	Sec. 5, Gregg CSL	9,565	Empire	1953	Gulf
Pecos	SOT	No. 2-1 Owens	Sec. 25, Blk. 178, TCRR	9,556	Empire	1953	SOT
Pecos	C. L. Hay	No. 1 Alexander	Sec. 86, Blk. 1C, H&GN	6,300	?	1953	Stanolind
Pecos	Stanolind	No. 1 Roxse-Abell Unit #2	Sec. 23, Blk. 9, Lot 7, H&GN	5,435	Empire	1953	Stanolind
Pecos	Stanolind	No. 1 I. T. Pryor	Sec. 100, Blk. OW, GC&SF	5,290	?	1953	Stanolind
Pecos	Humble	No. 1 State Univ. "AG"	Sec. 18, Blk. 18, Univ. Lands	7,350	Humble	1954	Humble
Pecos	Houston	No. 1 Trees	Sec. 54, Blk. 8, H&GN	4,803	Empire	1954	Stanolind
Polk	SOT	No. 1 A. L. Luthe	A. L. Luthe, 1.185 Ac. Tr., M. C. Tracy	10,992	Delta	1952	SOT
Presidio	Gulf	No. 1 Mitchell	Sec. 40, Blk. 1, TWNG	15,805	GR&DC	1952	GR&DC
Reagan	Phillips	No. 1 University "ZZ"	Sec. 16, Univ. Blk. 6	11,830	Texaco	1954	Texaco
Reagan	Big Lake Oil	?	Big Lake Field	8,000	McCollum	1940	Plymouth
Reagan	Atlantic	No. 48F University	Sec. 14, Blk. 48, Univ.	9,770	Atlantic	1953	Atlantic
Reagan	Humble	No. 1-L Sawyer Cattle Co.	Sec. 107, Blk. 1, T&P	9,546	Humble	1953	Humble
Reagan	Amerada	No. 2 Hickman	Survey 1, HE&WT	10,077	GRC	1954	Amerada
Reagan	Texas Gulf Producing	No. 1 TXL	330 FNL, 440 FWL, 227, B. 1, T&P	10,877	SSC	1954	Texas Gulf
Reagan	Amerada	No. 1 G. O. Mitchell	Sec. 4, Blk. "H," L&SV	12,490	Empire	1954	Stanolind
Reeves	Buffalo	No. 1 Lindley	Sec. 8, Blk. 56, TSP 3, T&P	3,365	Gulf	1953	Gulf
Reeves	Gulf	No. 1 P. G. Northrup et al.	Sec. 33, Blk. 50, TSS, T&P	16,630	Gulf	1953	Gulf
Reeves	Magnolia	No. 1 Rape	Sec. 24, Blk. C-1, PSL	11,247	Magnolia	1953	Magnolia
Reeves	Gulf	No. 1 Shurtleff	Sec. 20, Blk. C-17, PSL	14,710	Empire	1954	Gulf
Reeves	Hill & Meeker	No. 1 Settle	Sec. 38, Blk. 55, T1N, T&P	4,015	Empire	1954	?
Refugio	Shell	No. 1 M. V. O'Connor Tr. 15	Robert Wilson, A-417	7,150	Petty	1955	Shell
Roberts	Cree	No. 1 Locke	Sec. 102, Blk. M-Z, BS&F	4,252	GR&DC	1952	GR&DC
Roberts	Gulf	No. 1 Haggard	Sec. 5, Blk. Z, I&GN	9,305	GR&DC	1952	GR&DC
Roberts	Cree	No. 1 Carter	Sec. 110, Blk. 2, I&GN	4,157	GR&DC	1952	GR&DC

County	Company	Lease	Location	Survey Depth	Shot by	Date	Sponsored by
Roberts	Glenn McCarthy	No. 1 J. D. Lard	Sec. 3, 660' fm S&E Lines BBB&C	9,984	Gulf	1954	Gulf
Runnels	Gulf	No. 2 Stehle	Forsyth Blk. 450	4,455	GR&DC	1953	GR&DC
Runnels	American Trade & Prod.	M. W. McShan	Sec. 233, R. M. Williamson	4,582	Southern	1953	AT&P
Runnels	Gulf	No. 1 T. Puckett	Sec. 86, Blk. 64, H&TC	5,830	Empire	1954	Gulf
Runnels	Gulf	No. 1-A G. Seitz	Sec. 81, Blk. 64, H&TC	5,380	Empire	1954	Gulf
Runnels	Gulf	No. 1 M. Pumphrey	Sec. 83, Blk. 64, H&TC	5,360	Empire	1954	Gulf
Runnels	Gulf	No. 1 J. Barron	Blk. 450, L. Forsyth Survey	5,385	Empire	1954	Gulf
Runnels	Gulf	No. 1 A. L. Mitchell	Sec. 107, Blk. 64, H&TC	5,380	Empire	1954	Gulf
Runnels	Gulf	No. 1 J. O. Sanford	Blk. 450, L. Forsyth Survey	4,505	Empire	1954	Gulf
Rush	Skelly	No. 1 G. W. Weatherly	W. M. McShine Surv., A-528	8,158	SSC	1954	SSWSA
Sabine	Benedum-Trees	No. 1 Temple Lbr. Co.	William W. Davis A-89	11,075	SSC	1954	SSWSA
Sabine	Stephens	No. 1 Cox	Naomi Mackey Survey	8,045	?	1953	Stanolind
Sabine	Benedum & Trees	No. 1 Temple Lbr. Co.	Wm. Davis Surv. A-89	10,500	Sohio	1954	SSWSA
San Augustine	Stanolind	No. "A" 1, J. H. Fox	Wm. White Survey	8,997	?	1953	Stanolind
San Augustine	Lester & Culbertson	No. 1 Childers	Chaplin Survey	10,028	?	1953	Stanolind
San Augustine	Stanolind	No. 1 Clara Bohanan	Mathew Parker Survey	8,478	Western	1953	Stanolind
San Jacinto	Stanolind	No. 1-B Emily Langham	J. T. Simpson, A-49	12,070	Shell	1952	SSWSA
Schleicher	Head & Welch	No. 1 Boyd	Sec. 15, Blk. "H," GH&SA	5,300	?	1952	Stanolind
Schleicher	Sinclair	No. 1-101 University	Sec. 22, Blk. 54, University	7,780	?	?	Sinclair
Schleicher	Sinclair	No. 1 S. J. Hall	Sec. 5, Tom Green CSL	6,414	?	?	Sinclair
Schleicher	Marsh	No. 1 Davis	Sec. 9, Blk. A, GS&SF	8,589	?	?	Sinclair
Schleicher	Gen. American	No. 1 Thompson	Sec. 43, Blk. 4, HE&WT	7,233	?	?	Sinclair
Schleicher	King-Eisner	No. 1 Meckel	Sec. 66, Blk. T	7,100	?	?	Stanolind
Schleicher	Humble	No. 1 M. M. Reynolds	Sec. 42, Blk. I, GH&SA RR Sur.	6,340	Humble	1954	Humble
Schleicher	Scherck & Chizum	No. 1 D. C. O. Wilson	Sec. 9, Blk. V-14, W. H. Maulding	7,150	Empire	1954	SOT
Schleicher	Taylor Oil & Gas	No. 1 Judkins	Sec. 18, Blk. A, MB&M Survey	6,600	Empire	1954	SOT
Schleicher	Marsh	No. 1 Willoughby	Sec. 11, Blk. 2, GC&SF	9,300	Magnolia	1953	Magnolia
Schleicher	Magnolia	No. 1 Mary Ball	Sec. 50, Blk. A, GH&SA RR	4,841	Magnolia	1954	Magnolia
Scurry	Texaco	No. 2 M. A. Fuller	Sec. 606, Blk. 97, H&TCRR	8,120	Texaco	1953	Texaco
Scurry	Sunray	No. 1 Criswell	Sec. 212, Blk. 2, H&TC	7,229	SSC	1952	Sunray
Scurry	Lion	No. 2 Strom	Sec. 108, Blk. 97	6,497	Tomlinson	1950	Lion
Scurry	Blount Drlg. Co.	No. 1 Cary	Sec. 111, Blk. 97, H&TC	7,700	Donnally	1953	Shell
Scurry	Humble	No. 1 A. Jones	Sec. 487, Blk. 97, H&TC	8,362	Humble	1953	Humble
Scurry	R. Olsen Oil	D. D. Feldman	Sec. 63, Blk. 3, H&TC	7,360	Southern	1953	Amer. Trad.
Shelby	Amerada	No. 1 Lula Bell Strickland	Richard Ryan, A-216	11,648	Shell	1954	SSWSA
Sherman	Humble	No. 1 Hannah Morris	Sec. 79, Blk. 1-T, T&NO Sur.	6,090	Tex. Seis	1954	Humble
Stonewall	American Trading & Prod.	No. 1 Letz	M. D. Hemphill Surv.	6,225	Southern	1952	Amer. Trad
Sutton	Norsworthy	No. 1 Morris	Sec. 82, Blk. "C," HE&WT	7,660	General	1953	Shell
Sutton	Shell	No. 1 Aldwell	No. 14, V. F. Young	10,425	Shell	1953	Shell
Sutton	Norsworthy	No. 1 Meckel	Sec. 123, Blk. C, HE&WT	8,220	?	?	Sinclair
Sutton	Norsworthy	No. 1 Sawyer	Sec. 170, Blk. C, HE&WT	9,698	Sinclair	1953	Sinclair
Sutton	Sinclair	No. 1 Thorpe	Sec. 2, Ab. 1543, GC&SF	7,780	Sinclair	1953	Sinclair
Sutton	Tenn. Prod.	No. 1 Jones	Sec. 156, Blk. A, HE&WT	7,800	?	?	Sinclair
Sutton	Sinclair	No. 2 B. Hunt	Sec. 71, Blk. 14, TW&NG	6,500	?	?	Sinclair
Sutton	SW Natl. Prod. et al.	No. 1 Ross	Sec. 14, Blk. 14	5,735	?	1953	Stanolind
Sutton	Humble	No. 1 D. J. Harrison	Sec. 115, CCSD&RGNG RR Surv.	6,970	Humble	1954	Humble
Sutton	Ada Oil Company	No. 1 Rip Ward	Sec. 92, Blk. B, HE&WT	7,205	Empire	1954	Stanolind
Terrell	Humble	No. 1 N. D. Blackstone	Sec. 58, CCSD&RGNG RR Surv.	10,200	Humble	1953	Humble
Terry	O'Neill	No. 1 Cotton	Sec. 61, Blk. DD, Gibson Surv.	10,503	?	1952	Stanolind
Terry	Humble	No. 1 Wilmeth	Sec. 44, Blk. K, PSL Surv.	13,200	Humble	1954	Humble
Terry	Anderson-Prichard	No. 1 Oil Development Co.	Sec. 152, Blk. D-11, D&P RR	12,750	Empire	1954	Gulf
Tom Green	Cities Service	No. 1 Wash	Blk. K 106	6,347	Cities Serv.	1950	Cities Service
Tom Green	C. B. Drlg. Co. & A. Hickey	No. 1 Broome	Sec. 105, Washington CSL	6,100	?	1952	Stanolind
Tom Green	Cities Service	No. 1 Brenek	Sec. 169½, L. P. Moore	6,331	?	1952	Stanolind
Tom Green	Stanolind	No. 3-B Johnson	Sec. 20, Blk. 25, H&TC RR	4,877	?	1953	Stanolind
Tom Green	Bridwell, Perkins & Prothro	No. 2 Wilson	Sec. 6, W. Harris	6,437	Humble	1952	Humble

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Tom Green	Sinclair	No. 1 Stansberry	Sec. 61, Blk. 25, H&TC	5,805	?	?	Sinclair
Tom Green	SOT	No. 1 B. W. Moore et al.	Sec. 8383, J. Simpson Surv.	7,070	Empire	1953	SOT
Tom Green	Republic	No. 1 J. W. Johnson	Sec. 34, Blk. 25, H&TC	6,270	?	1953	Stanolind
Tom Green	Fuller & Fuller	No. 1 Johnson	C. M. Dunn Survey 536	5,759	?	1953	Stanolind
Tom Green	Mayfair Min.	No. 1 Pruett	C. S. Jackson Surv. 1823	6,503	?	1953	Stanolind
Tom Green	La Gloria	No. 1 Halfmann	Sec. 153, Blk. 11, SPRR	4,078	?	1953	Stanolind
Tom Green	Rowan Drilling Co	No. 1-A Jones	Sec. 888, J. Jung, Survey	6,520	?	1953	Stanolind
Tom Green	Humble	No. 1 Washington CSL Nasworthy	Washington CSL Tract 103	6,119	Humble	1954	Humble
Tom Green	Honolulu	No. 1 Hoblett Jackobs	Sec. 2, S. E. White #1 Surv.	7,650	United	1954	Honolulu
Tom Green	Norsworthy	No. 1 Johnson	Sec. 1132, Flowers Survey	6,756	Empire	1953	Stanolind
Tom Green	Ryan & Burk	No. 1 Johnson	Sec. 11, Blk. 24, H&TC	6,047	Empire	1954	Stanolind
Tom Green	Texas Crude	No. 1 DeWolf	Sec. 1008, HE&WT Surv.	6,375	Empire	1954	Stanolind
Tom Green	McMahon	No. 1 Southern Pine	Sec. 4, W. A. Treadgill	5,802	Empire	1954	Stanolind
Trinity	Quinta Petr. Corp.	No. 1 State "AO"	J. M. Walker Surv. A-640	8,159	Petty	1952	Shell
Upton	Texaco	No. 1-AR University	Sec. 3, Univ. Blk. 5	11,450	Texaco	1953	Texaco
Upton	Cities Service	No. 1 Corbett	Sec. 3, Blk. 58, Univ.	12,399	Empire	1953	Cities Service
Upton	Woodward & Co.	No. 2 McElroy Ranch "H"	Sec. 11, Blk. B-2, GC&SF	10,800	National	1952	TPC&O
Upton	Gulf	No. 1 McElroy Ranch	Sec. 40, Blk. 42, T5S, T&P	14,350	GR&DC	1952	GR&DC
Upton	Gulf	No. 362-D McElroy	Sec. 182, Blk. "E," CCSD&RGNG	11,750	GR&DC	1952	GR&DC
Upton	Gulf	No. 1 University	Sec. 187, Blk. "F," CCSD&RGNG	10,011	GR&DC	1953	GR&DC
Upton	Vickers	No. A-1 Hanks	Sec. 13, Blk. 5, University	11,530	Midland	1953	Shell
Upton	Pure	No. 1 Graf	Sec. 52, Blk. C, CCSD&RGNG	13,255	Empire	1953	Pure
Upton	Texas	No. 2-D McElroy Ranch	Sec. 102, Blk. D, CCSD&RGNG	12,480	Empire	1953	Forest
Upton	Gulf	No. 1-N McElroy Ranch	Sec. 182, Blk. "E," CCSD&RGNG	9,950	Empire	1953	Gulf
Upton	Gulf	No. 3-D McElroy Ranch	Sec. 72, Blk. "Y," TCRR	13,200	Gulf	1953	Gulf
Upton	TPC&O	No. 1 Anna Egolf	Sec. 182, Blk. "E," CCSD&RGNG	10,200	Gulf	1953	Gulf
Upton	Gulf	No. 1 TXL "AE"	Sec. 3, J. H. Gibson Surv.	11,055	Gulf	1953	Gulf
Upton	Hunt	No. 1-105 Amacker	Sec. 31, Blk. 42, T5S, T&P	11,220	Gulf	1953	Gulf
Upton	Rep. Nat. Gas & Seaboard	No. 2 University	Sec. 105, Blk. D, CCSD&RGNG	11,930	Portable	1954	Hunt
Upton	Vickers	No. 1 Powell	Sec. 18, Blk. 15, University	11,245	?	1952	Seaboard
Upton	Gulf	No. 4-D McElroy Ranch "State"	Sec. 19, Blk. 40, T5S, T&P	11,224	?	1953	Sinclair
Upton	Gulf	No. 4-D McElroy Ranch Co. "C"	Sec. 182, Blk. E, CCSD&RGNG	10,740	Gulf	1954	Gulf
Upton	Gulf	No. 1 State "ER"	Sec. 183, Blk. E, CCSD&RGNG	10,935	Gulf	1954	Gulf
Upton	Gulf	No. 5-E McElroy Ranch "State"	Sec. 26, Blk. 4, University	11,500	Gulf	1954	Gulf
Upton	Gulf	No. 365-E McElroy Ranch Co.	Sec. 182, Blk. E, CCSD&RGNG	11,495	Gulf	1954	Gulf
Upton	Gulf	No. 2D-S McElroy Ranch Co. "C"	Sec. 195, Blk. F, CCSD&RGNG	12,900	Gulf	1954	Gulf
Val Verde	Phillips	No. 1 Delta-Wilson	Sec. 183, Blk. E, CCSD&RGNG	10,800	Gulf	1954	Gulf
Van Zandt	Pure	No. 8-D O. L. Swain II	Sec. 82, Blk. E, GC&SF RR Surv.	15,800	SGC	1952	Phillips
Victoria	Monterey Exp. Co.	No. 1 Agnes Murphy	John Walling, A-891	11,300	Petty	1952	SSWSA
Ward	Gulf	No. 10 Wristen	Carlos & Rafael de la Garza Survey A-46	6,289	Petty	1954	Monterey
Ward	Humble	No. 1 State Univ. "AC"	Sec. 20, Blk. 5, H&TC	7,530	?	1953	?
Ward	Magnolia	No. 1 Univ. of Texas "B"	Sec. 28, Blk. 18, Univ. Lands	5,390	Humble	1954	Humble
Ward	Magnolia	No. 1-A Univ. "F"	Sec. 34, Blk. 17, Univ.	4,960	Magnolia	1954	Magnolia
Ward	Gulf	No. 319 O'Brien	Sec. 35, Blk. 17, Univ.	5,288	Magnolia	1954	Magnolia
Wheeler	Gulf	No. 1 J. L. Bailey "A"	Sec. 20, Blk. F, G&MMB&A	15,800	Gulf	1954	Gulf
Wheeler	Sinclair	No. 2 Mills	Sec. 20, Blk. A-5, H&GN	10,999	Gulf	1953	Gulf
Williamson	Shell	No. 1 S. E. Purcell	Sec. 4, Blk. A-7, H&GN	?	?	1954	Sinclair
Winkler	Cosden Petr. Co.	No. 1 S. B. Wight et al.	W. H. Magill, A-420	9,400	Shell	1954	Shell
Winkler	Magnolia	No. 1 Univ. No. 39854	Sec. 22, Blk. 40, PSL	12,005	Empire	1955	Cosden Petr. Co.
Winkler	Magnolia	No. 1 Univ. "D"	Sec. 11, Blk. 21, Univ.	8,540	Magnolia	1953	Magnolia
Winkler	Gulf	No. 1 State "GV"	Sec. 31, Blk. 21 Univ.	5,240	Magnolia	1954	Magnolia
Wise	Tom B. Medders	No. 1 E. B. Clark	Sec. 43, Blk. 21, Univ.	5,125	Empire	1954	Gulf
Wood	Humble	No. 2 Yantis Gas Unit No. 3 Price	Abel Hodges A-370 (c. vel. log)	8,418	SSC	1954	Phillips
Yoakum	Wilshire-Lowe	No. 2 Weems	Jesse Walker Survey A-607	13,268	Humble	1954	SSWSA
Yoakum	Amerada		Sec. 342, Blk. D, Gibson	12,019	Seis. Service	1952	Wilshire
			Sec. 403, Blk. D, Gibson	11,751	GRC	1953	Amerada

County	Company	Lease	Location	Survey Depth	Shot by	Date	Sponsored by
Yoakum	Signal Oil & Gas	No. 1 Webb	Sec. 423, Blk. D, Gibson	11,503	IGI	1952	Signal
Yoakum	Coline Oil Corp.	No. 1-BB1 Willard	Sec. 881, Blk. D, J. H. Gibson	13,330	Texaco	1953	SSWSA
Yoakum	Texaco	No. 1 Fitzgerald	Sec. 429, Blk. D, Gibson Surv.	12,453	Texaco	1953	Texaco
Yoakum	Honolulu	No. 1 Fillingim	Sec. 661, Blk. D, Gibson	11,500	?	1952	Stanolind
Yoakum	Fulton	No. 1 Keller	Sec. 399, Blk. D, Gibson	11,946	?	?	Sinclair
Yoakum	Lawton	No. 1 McGinty	Sec. 454, Blk. D, Gibson	10,980	?	?	Sinclair
Yoakum	Livermore	No. 1 Fields	Sec. 347, Blk. D, Gibson	12,143	?	?	Sinclair
Yoakum	Hunt	No. 1 W. W. Johnson	Sec. 644, Blk. D, Gibson	11,525	Gulf	1954	Gulf
Yoakum	Stanolind	No. 1 G. E. Turrentine	Sec. 41, Blk. K, PSL	10,000	SSC	1954	Stanolind
Yoakum	Oceanic	No. 1 Graham	Sec. 268, Blk. D, Gibson	12,842	Empire	1954	Stanolind
Yoakum	Hunt	No. 1 Goggins	Sec. 191, Blk. D, Gibson	12,513	Empire	1954	Stanolind
Zapata	SOT	No. 1 Serapio Vela	5,300'FNW, 5,200'FSW, Grullo Gr.	14,700	Southern	1953	SOT
Zavalla	Shell	No. 1 H. C. Plumley	GC&SF RR, A-839	13,000	Shell	1953	Shell
Zavalla	Shell	No. 3 H. C. Plumley	GC&SF RR, A-839, Sec. 3	3,898	Shell Dev. Co.	1953	Shell
Zavalla	Phillips	No. 1 Zavala (Flowers & Ward)	I&GN Surv., Sec. 24	7,500	Petty	1953	Shell
			STATE OF SOUTH DAKOTA				
Dewey	Youngblood & Youngblood	No. 1 Galvin	Sec. 25, 16N-22E	6,305	Petty	1953	Shell
Dewey	Kerr-McGee	No. 1 Cook	Sec. 32, 13N-22E	5,990	Kerr-McGee	1954	Kerr-McGee
Haakon	Kerr-McGee	No. 1 Chute	Sec. 33, 3N-19E	5,484	Atlantic	1953	Atlantic
Harding	Shell Oil Co.	No. 1 State	Sec. 9, 21N- 4E	9,300	Petty	1953	Shell
Harding	Hunt Oil Co.	No. 1 Peterson	Sec. 7, 20N- 3E	9,000	Petty	1953	Shell
Meade	Lion Oil Co.	No. 1 Lou Libertin	Sec. 9, 4N-11E	4,200	Atlantic	1954	RMSWSA
Perkins	Shell Oil Co.	No. 1 H. D. Veal	Sec. 7, 17N-15E	8,280	Petty	1952	Shell
Perkins	Hunt Oil Co.	No. 1 Government	Sec. 8, 22N-11E	9,500	United	1954	RMSWSA
			STATE OF UTAH				
Grand	Equity Oil Company	No. 1 Donohue	Sec. 20, 23S-19E	6,610	National	1954	Conoco
San Juan	Shell	No. 1 Desert Creek	Sec. 2, 42S-23W	6,690	Shell	1954	Shell
Sevier	El Paso Natr. Gas Co.	No. 1 Salina Canyon	Sec. 15, 22S- 2E	6,115	GSI	1953	El Paso Natural
Unitah	Conoco	No. 1 Chapita Wells	Sec. 16, 9S-23E	9,514	Conoco	1952	Conoco
			STATE OF WASHINGTON				
Grays Harbor	Conoco	No. 1 State, Permit No. 11 Well	Sec. 36, 20N- 9W	3,895	GSI	1954	Conoco
Lewis	Standard of California	No. 1 Seifert Well	Sec. 4, 14N- 3W	4,016	GSI	1953	Standard of Calif.
Randolph	P. C. McKenzie	No. 1 Elk Horn Coal Co.	Middle Fork District	7,343	Petty	1955	Hope Nat. Gas Co.
Wood	Hope Natural Gas Co.	No. 9634 Well	Walker District	13,090	Petty	1955	Hope Nat. Gas Co.
			STATE OF WYOMING				
Big Horn	Gulf	No. 1 Emmett Fed.	Sec. 13, 52N- 93W	11,700	Gulf	1953	Gulf
Campbell	Trigood-Shell	No. 2 Hamm Unit	Sec. 33, 53N- 70W	8,484	Rayflex	1953	Shell
Campbell	Gulf	No. 1 Davis	Sec. 34, 51N- 72W	10,800	Gulf	1953	RMSWSA
Carbon	Roden, Darden & McRae	No. 1 Federal	Sec. 6, 20N- 77W	5,710	Conoco	1953	Conoco
Carbon	Ohio Oil Co.	No. 1 South Cedar Ridge	Sec. 22, 22N- 85W	12,100	Ohio	1953	RMSWSA
Converse	Texaco	No. 1 Gov't. Van Arsdale	Sec. 18, 32N- 71W	10,313	Texaco	1954	RMSWSA
Converse	Union Oil & Brazos	No. 1 Moore Sheep Co.	Sec. 4, 40N- 76W	13,500	Union	1953	RMSWSA
Fremont	Sohio	No. 1 Gov't. Smith	NE SW Sec. 27, 31N- 95W	7,343	Sohio	1952	Sohio
Fremont	Gulf	No. 1 Mae Rhoades	Sec. 3, 3N- 2E	10,450	Gulf	1953	Gulf
Goshen	S. D. Johnson	No. 1 Gov't. (Shuppon)	Sec. 22, 19N- 64E	8,919	Pet. Geoph.	1953	The Chicago Corp.
Hot Springs	Ajax	No. 1 Anderson Moore	Sec. 9, 43N-100W	1,907	Hiawatha	1953	Hiawatha
Johnson	Conoco	No. 1 South Buffalo Unit	Sec. 24, 50N- 82W	13,135	United	1953	RMSWSA
Johnson	Chicago Corporation	No. 1 Gov't.	Sec. 34, 43N- 78W	14,000	Chicago	1953	RMSWSA
Laramie	Ginther, Warren & Ginther	No. 1 Fritz	Sec. 36, 14N- 61W	9,005	Union	1953	RMSWSA

County	*Company*	*Lease*	*Location*	*Survey Depth*	*Shot by*	*Date*	*Sponsored by*
Laramie	Pure	No. 1 Hixenbaugh	SE SW NE Sec. 34, 16N- 61W	7,900	WGC	1952	RMSWSA
Lincoln	El Paso Nat. Gas-Conoco	No. 1 Fontenelle	Sec. 11, 24N-113W	13,210	Conoco	1954	Conoco
Natrona	Forest Oil Company	No. 3 Grieve Unit	Sec. 28, 32N- 85W	7,273	Forest	1954	Forest
Park	Richfield Oil Corp.	No. 1 Frost Ridge Unit	NW NW Sec. 6, 50N-101W	8,121	WGC	1953	Richfield
Park	Sohio	No. 1 Gov't. Simmons	NW NW SE Sec. 13, 50N-100W	8,900	United	1954	Sohio (RMSWSA)
Park	Trigood	No. 1 Meeteetse	Sec. 28, 49N- 99W	11,333	United	1954	Atlantic
Sheridan	Cyprus Mining	No. 1 State	Sec. 16, 57N- 82W	9,543	Rayflex	1953	Shell
Sheridan	CM&W	No. 1A Haywood	Sec. 35, 58N- 84W	5,700	Rayflex	1954	Shell
Sheridan	McDermott	No. 6 Baker	Sec. 19, 58N- 84W	5,235	Rayflex	1954	Shell
Sweetwater	Texas	No. 5 Table Rock	Sec. 2, 18N- 98W	10,020	Gulf	1953	RMSWSA
Sweetwater	General Petr.	East Salt Well	Sec. 24, 14N-101W	7,700	GP	1954	RMSWSA
Sweetwater	Gulf	No. 1 Mae Rhoades	Sec. 3, 3N- 2E	10,450	Gulf	1953	Gulf
Sweetwater	Shell	No. 42-28 Shell Creek Unit	Sec. 28, 14N- 96W	5,355	Shell	1953	Shell
Washakie	Sohio	No. 1 Bruce Unit	NW SW NW Sec. 7, 43N- 89W	5,151	Keystone	1953	RMSWSA
Washakie	California Co.	No. 1 Neiber Dome Unit	Sec. 14, 45N- 93W	10,230	Gulf	1953	Gulf

STATE OF WEST VIRGINIA

Randolph	P. C. McKenzie	No. 1 Elk Horn Coal Co.	Middle Fork District	7,343	Petty	1955	Hope Nat. Gas Co.
Wood	Hope Natural Gas Co.	Well No. 9634	Walker District	13,090	Petty	1955	Hope Nat. Gas Co.

FOREIGN COUNTRIES

BRAZIL, SOUTH AMERICA

Amazonas	Petrobras	No. 1-AZ Nova Olinda	150 km SE of Manaus, Amazonas	1,845 M	GSI	1950	Petrobras
Bahia	Conselho Natl. do Petr.	No. C-82-BA Candeias	Candeias	2,305 M	GSI	1951	Con. N. do Petr.
Bahia	Conselho Natl. do Petr.	No. PV-5-BA Paramarin	Candeias	1,154.3M	GSI	1951	Con. N. do Petr.
Bahia	Conselho Natl. do Petr.	No. PJ-1-BA Pojuca	1 km NW of Pojuca, Bahia	1,514 M	GSI	1952	Con. N. do Petr.
Bahia	Conselho Natl. do Petr.	No. EM-1-BA Eugenho do Meio	Candeias	1,428 M	GSI	1954	Con. N. do Petr.
Para	Conselho Natl. do Petr.	No. LM-1-PA Limoeiro	120 km SW of Belem, Para	4,020 M	GSI	1951	Con. N. do Petr.
Para	Conselho Natl. do Petr.	No. CR-1-PA Cururu	Marajo Basin	4,037 M	GSI	1952	Con. N. do Petr.
Para	Conselho Natl. do Petr.	No. BJ-1-PA Badajos	100 km SE of Belem (Rio Capim)	2,186.3M	GSI	1953	Con. N. do Petr.
Para	Petrobras	No. AC-1-PA (AZ) Alter do Chao	50 km of Santarem, Para	2,285 M	GSI	1954	Petrobras
Serigipe	Conselho Natl. do Petr.	No. MR-3-SE Maracuja	16 km E of Japaratuba, Serigipe	1,277 M	GSI	1952	Con. N. do Petr.

CANADA

Alberta	A. G. Bailey	No. 1 Bailey-Morningside	LSD 3, Sec. 14, T42, R27, W4M	7,300	WGC	1950	Calif. Std.
Alberta	Stanolind	No. 1 Otterlake	LSD 31, Sec. 29, T88, R13, W5M	5,324	WGC	1952	Standlind
Manitoba	Calif. Std.	No. 9-13 Waskada	LSD 9, Sec. 13, T1, R26, WPM	5,170	WGC	1952	Calif. Std.
Manitoba	Souris Valley	No. 1 Robert Moore	LSD 5, Sec. 20, T1, R27, WPM	5,856	GSI	1949	Souris
Manitoba	Owen Drilling Co.	No. 1 J. P. Owen	LSD 8, Sec. 11, T2, R22, WPM	3,588	WGC	1952	Calif. Std.
Manitoba	Royalite Triad et al.	No. 1 East Hartney	LSD 7, Sec. 27, T5, R24, WPM	3,980	WGC	1952	Calif. Std.
Manitoba	Calif. Std.	No. 10-33 Hartney	LSD 16, Sec. 33, T5, R24, WPM	5,136	GSI	1950	Calif. Std.
Manitoba	Calif. Std.	No. 7-27 Reston	LSD 7, Sec. 27, T6, R27, WPM	3,287	WGC	1952	Calif. Std.
Manitoba	Calif. Std.	No. 9-26 Findlay	LSD 9, Sec. 26, T7, R25, WPM	4,056	WGC	1952	Calif. Std.
Manitoba	Calif. Std.	No. 2-21 Linklater	LSD 2, Sec. 21, T7, R28, WPM	4,960	WGC	1952	Calif. Std.
Manitoba	Calif. Std.	No. 5-18 Woodnorth Prov.	LSD 5, Sec. 18, T9, R27, WPM	3,646	WGC	1952	Calif. Std.
Manitoba	Calif. Std.	No. 15-16 Hargrave	LSD 15, Sec. 16, T11, R27, WPM	2,927	WGC	1951	Calif. Std
Manitoba	Langford Oil Syndicate	No. 1 Langford Syndicate	LSD 5, Sec. 29, T14, R14, WPM	2,490	GSI	1948	
Manitoba	Homestead-Long Island	No. 1 Birdtail	LSD 9, Sec. 21, T15, R27, WPM	3,395	United Geo.	1953	Imperial Oil Ltd.
Manitoba	Imperial Oil Ltd.	No. 1 Birtle	LSD 1, Sec. 27, T17, R26, WPM	4,254	IOL Party	1951	Imperial Oil Ltd.
Manitoba	Imperial Oil Ltd.	No. 1 Imp. Madeline	LSD 16, Sec. 18, T18, R29, WPM	4,456	IOL Party #33	1951	Imperial Oil Ltd.
Saskatchewan	Socony Woodley	Southern Gainsborough	LSD 16, Sec. 19, T1, R30, WPM	4,780	United Geo.		Socony Vacuum
Saskatchewan	Socony Imperial Western Prairie	No. 1 Carievale	LSD 16, Sec. 4, T3, R32, WPM	8,322	GSI	1952	Socony Vacuum

County	*Company*	*Lease*	*Location*	*Survey Depth*	*Shot by*	*Date*	*Sponsored by*
Saskatchewan	Socony Woodley Southern	No. 30-3 Bellegarde	LSD 3, Sec. 30, T6, R31, WPM	3,500	United Geo.	1954	Socony Vacuum
Saskatchewan	Socony Woodley Southern	No. 11-5 St. Antoine	LSD 3, Sec. 11, T6, R32, WPM	3,714	United Geo.	1954	Socony Vacuum
Saskatchewan	Socony Western Prairie	No. 1 Redvers	LSD 13, Sec. 36, T7, R32, WPM	3,890	ECI	1952	Socony Vacuum
Saskatchewan	Tidewater Imperial	No. 1 Wawata Crown	LSD 2, Sec. 12, T11, R34, WPM	3,920	United Geo.	1954	Tidewater
Saskatchewan	Socony Sohio	No. 1 Kessook	LSD 5, Sec. 11, T25, R33, WPM	2,776	United Geo.	1953	Socony Vacuum
Saskatchewan	Socony Central Del Rio	No. 1 Ratcliffe	LSD 5, Sec. 30, T1, R15, W2M	9,479	ECI	1952	Socony Vacuum
Saskatchewan	Calif. Std.	No. 5-21 Federated Coop	LSD 5, Sec. 21, T2, R4, W2M	8,280	SSX	1953	Calif. Std.
Saskatchewan	J. P. Owen	No. 1 Kincaid	LSD 12, Sec. 16, T2, R7, W2M	5,900	Beaver Geo.	1951	Shell Oil
Saskatchewan	Shell Oil Company	No. 1 Oungre	LSD 7, Sec. 1, T2, R14, W2M	6,240	Beaver Geo.	1953	Shell Oil
Saskatchewan	Socony Central Del Rio	No. 1 Lake Alma	LSD 6, Sec. 10, T3, R17, W2M	6,075	United Geo.	1953	Socony Vacuum
Saskatchewan	Sohio Standard	No. 1 Buffalo Gap	LSD 16, Sec. 10, T3, R25, W2M	7,722	Seismotech	1952	Sohio
Saskatchewan	Shell Oil Company	No. A-12-25 Elswick	LSD 12, Sec. 25, T4, R12, W2M	5,300	SSX	1953	Shell Oil
Saskatchewan	Shell Oil Company	No. A-1-4 Minard	LSD 1, Sec. 4, T5, R7, W2M	5,100	SSX	1953	Shell Oil
Saskatchewan	Shell Oil Company	No. 16-35 Kilgore	LSD 16, Sec. 35, T5, R11, W2M	5,182	SSX	1953	Socony Vacuum
Saskatchewan	Bennett & Burns	No. 1 Ben L. Young Bell	LSD 11, Sec. 19, T5, R14, W2M	5,045	ECI	1953	Socony Vacuum
Saskatchewan	Shell Oil Company	No. 1 Ceylon	LSD 10, Sec. 34, T5, R20, W2M	5,901	Beaver Geo.	1952	Shell
Saskatchewan	Socony Sohio	No. 1 Roe	LSD 5, Sec. 28, T5, R21, W2M	6,754	United Geo.	1953	Socony Vacuum
Saskatchewan	Tidewater Imperial	No. 1 Lampman Crown	LSD 5, Sec. 28, T6, R6, W2M	5,618	United Geo.	1953	Tidewater
Saskatchewan	Shell Oil Company	No. A-7-18 Midale	LSD 7, Sec. 18, T6, R10, W2M	4,990	Century Geo.	1953	Shell
Saskatchewan	Shell Oil Company	No. A-5-32 Halbrite	LSD 5, Sec. 32, T6, R11, W2M	4,972	SSX	1954	Shell
Saskatchewan	Shell Oil Company	No. A-1-13 Brooking	LSD 1, Sec. 13, T6, R19, W2M	5,300	SSX	1953	Shell
Saskatchewan	Socony Sohio	No. 1 Ritchie	LSD 6, Sec. 2, T6, R23, W2M	6,383	United Geo.	1953	Socony Vacuum
Saskatchewan	Sohio Standard	No. 1 Viceroy	LSD 16, Sec. 11, T6, R25, W2M	7,850	Seismotech	1952	Sohio
Saskatchewan	Shell Oil Company	No. A-1-12 Viewfield	LSD 1, Sec. 12, T7, R9, W2M	4,807	SSX	1953	Shell
Saskatchewan	Shell Oil Company	No. A-8-30 Griffen	LSD 8, Sec. 30, T7, R11, W2M	4,964	SSX	1954	Shell
Saskatchewan	Socony Central Del Rio	No. 1 Grassdale	LSD 6, Sec. 2, T7, R16, W2M	5,335	United Geo.	1954	Socony Vacuum
Saskatchewan	Socony Sohio	No. 1 Verwood	LSD 9, Sec. 9, T7, R28, W2M	8,154	United Geo.	1953	Socony Vacuum
Saskatchewan	Tidewater Imperial	No. 1 Arcola Crown	LSD 1, Sec. 22, T8, R4, W2M	4,873	United Geo.	1953	Tidewater
Saskatchewan	Shell Oil Company	No. 1 Estevan	LSD 6, Sec. 24, T8, R9, W2M	4,440	Century Geo.	1953	Shell
Saskatchewan	Socony	No. 1 Weyburn	LSD 8, Sec. 11, T8, R14, W2M	5,500	United Geo.	1953	Socony Vacuum
Saskatchewan	Shell Oil Company	No. 1 Pangman	LSD 9, Sec. 28, T8, R21, W2M	7,665	Discovery Geo.	1953	Shell
Saskatchewan	Socony Sohio	No. 10-11 Readlyn	LSD 11, Sec. 10, T8, R28, W2M	4,480	United Geo.	1954	Socony Vacuum
Saskatchewan	Tidewater	No. 4-11 Forget Crown	LSD 4, Sec. 11, T9, R7, W2M	4,380	United Geo.	1953	Tidewater
Saskatchewan	Shell Oil Company	No. 1 (Run #1) Dahinda	LSD 6, Sec. 2, T9, R23, W2M	5,244	Velocity Surv.	1951	Shell
Saskatchewan	Shell Oil Company	No. 1 (Run #2) Dahinda	LSD 6, Sec. 2, T9, R23, W2M	6,805	Beaver Geo.		Shell
Saskatchewan	Shell Oil Company	No. A-1-11 Dahinda	LSD 1, Sec. 11, T9, R23, W2M	5,150	SSX	1953	Shell
Saskatchewan	Sohio	No. 11-15 Creelman	LSD 15, Sec. 11, T10, R11, W2M	4,500	R. H. Ray	1953	Sohio
Saskatchewan	Socony Sohio	No. 1 Crystal Hill	LSD 3, Sec. 14, T10, R24, W2M	6,314	United Geo.	1953	Socony Vacuum
Saskatchewan	Calif. Std.	No. 6-30 Fillmore	LSD 6, Sec. 30, T11, R9, W2M	4,672	SSX	1953	Calif. Std.
Saskatchewan	Socony Sohio	No. 1 Mossbank	LSD 13, Sec. 27, T11, R28, W2M	6,000	United Geo.	1953	Socony Vacuum
Saskatchewan	Tidewater Imperial	No. 1 Bender Crown	LSD 13, Sec. 11, T12, R5, W2M	4,550	Petty Geo.	1952	Tidewater
Saskatchewan	Socony	No. 1 Avonlea	LSD 15, Sec. 7, T12, R21, W2M	7,543	GSI	1952	Socony Vacuum
Saskatchewan	Socony Sohio	No. 2 Avonlea	LSD 15, Sec. 20, T12, R22, W2M	5,050	General Geo.	1952	Socony Vacuum
Saskatchewan	B. A. Husky Phillips	No. 1 Bemersyde	LSD 3, Sec. 11, T13, R8, W2M	5,737	Delta Exp.	1952	Calif. Std.
Saskatchewan	Sohio Standard	No. 1 Leakville	LSD 4, Sec. 11, T14, R26, W2M	6,182	R. H. Ray	1952	Sohio
Saskatchewan	Imperial Tidewater	No. 4-3 Wapella	LSD 4, Sec. 3, T15, R1, W2M	3,100	Indep. Exp.	1952	Imperial
Saskatchewan	Imperial Tidewater	No. 12-17 Broadview	LSD 14, Sec. 17, T15, R1, W2M	3,580	United Geo.	1953	Imperial
Saskatchewan	B. A. Husky Phillips	No. 1 Montmartre	LSD 12, Sec. 11, T15, R11, W2M	4,325			British American
Saskatchewan	Socony Sohio	No. 1 Estlin	LSD 1, Sec. 20, T15, R19, W2M	4,555	United Geo.	1953	Socony Vacuum
Saskatchewan	Socony Sohio	No. 1 Buttress	LSD 8, Sec. 4, T15, R28, W2M	6,668	United Geo.	1953	Socony Vacuum
Saskatchewan	Imp. Tidewater	No. 13-25 Oakshela	LSD 13, Sec. 25, T16, R6, W2M	3,255	United Geo.	1955	Imperial
Saskatchewan	Calif. Std.	No. 8-33 Ochapawace	LSD 8, Sec. 33, T17, R3, W2M	2,800	United Geo.	1954	Calif. Std.
Saskatchewan	Sohio Standard	No. 1 Pense	LSD 14, Sec. 10, T17, R22, W2M	6,014	R. H. Ray	1951	Sohio
Saskatchewan	B. A. Husky Phillips	No. 1 Ellisboro	LSD 8, Sec. 36, T18, R10, W2M	5,067			British American
Saskatchewan	Tidewater Imperial	No. 1 Cotham	LSD 1, Sec. 2, T19, R4, W2M	2,548	Indep. Exp.	1952	Imperial
Saskatchewan	Sohio Oil	No. 2 Venn	LSD 4, Sec. 28, T20, R24, W2M	4,400	Petty Geo.	1951	Sohio

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Saskatchewan	Sohio Oil	No. 1 Devil's Lake	LSD 16, Sec. 9, T30, R5, W2M	2,541	SSC	1950	Sohio
Saskatchewan	Socony Sohio	No. 1 Copeland	LSD 6, Sec. 13, T30, R20, W2M	4,215	United Geo.	1954	Socony Vacuum
Saskatchewan	Sohio	No. 1 Young	LSD 15, Sec. 11, T32, R27, W2M	4,240	West Provincial	1951	Sohio
Saskatchewan	Sohio Standard	No. 1 Quill Lake	LSD 15, Sec. 11, T35, R17, W2M	3,513	West Prov.	1951	Sohio
Saskatchewan	Sohio	No. 1 Nut Mountain	LSD 1, Sec. 28, T36, R10, W2M	3,004	SSC	1950	Sohio
Saskatchewan	Sohio	No. 1 Marysbury	LSD 16, Sec. 29, T38, R22, W2M	4,155	West Prov.	1951	Sohio
Saskatchewan	Britalta	No. 1 Pelican Lake	LSD 2, Sec. 2, T44, R26, W2M	3,097	United Geo.	1952	Imperial Oil
Saskatchewan	Husky Phillips	No. 1 Peesane	LSD 9, Sec. 22, T45, R12, W2M	2,500	ECI	1950	
Saskatchewan	Britalta	No. 1 MacDowall	LSD 2, Sec. 1, T46, R28, W2M	2,559	Northwest Seismic	1952	
Saskatchewan	Hudson's Bay	No. 1 Gronlid	LSD 15, Sec. 32, T47, R17, W2M	2,589	Atlantic Refg.	1950	Hudson's Bay
Saskatchewan	Shell Oil	No. 9 Wood Mountain	LSD 14, Sec. 9, T1, R8, W3M	4,775	SSX	1953	Shell
Saskatchewan	Shell Oil	No. 2 Wood Mountain	LSD 13, Sec. 36, T1, R12, W3M	6,025	GSI	1952	Shell
Saskatchewan	Shell Albercan	No. 2 Govenlock	LSD 16, Sec. 3, T1, R29, W3M	5,495	Nance Exp.	1953	Shell
Saskatchewan	Shell	No. 6 Wood Mountain	LSD 4, Sec. 13, T2, R7, W3M	5,435	Discovery Geo.	1953	Shell
Saskatchewan	Imperial McCarty Coleman	No 15-31 Masefield	LSD 15, Sec. 31, T2, R14, W3M	4,400	United Geo.	1953	Imperial
Saskatchewan	Shell	No. 1 Barclay Supreme	LSD 7, Sec. 2, T2, R28, W3M	6,612	Beaver Geo.	1952	Shell
Saskatchewan	Shell	No. 11 Wood Mountain	LSD 10, Sec. 15, T3, R6, W3M	5,660	SSX	1953	Shell
Saskatchewan	Shell	No. 12 Wood Mountain	LSD 16, Sec. 35, T3, R6, W3M	5,740	SSX	1953	Shell
Saskatchewan	Shell	No. 5 Wood Mountain	LSD 10, Sec. 11, T3, R9, W3M	5,501	Northwest Seismic	1953	Shell
Saskatchewan	Imperial-Tidewater	No. 6-10 Climax	LSD 6, Sec. 10, T3, R18, W3M	8,452	United Geo.	1953	Imperial
Saskatchewan	Imperial Canada Southern Federated Coop Calvan	No. 4-31 Battle Creek	LSD 4, Sec. 31, T3, R20, W3M	7,320	United Geo.	1952	Imperial
Saskatchewan	Sohio Standard	No. 1 Wood Mountain	LSD 16, Sec. 10, T4, R4, W3M	7,983	R. H. Ray	1951	Sohio
Saskatchewan	Shell	No. 4 Wood Mountain	LSD 4, Sec. 23, T4, R9, W3M	5,245	Discovery Geo.	1953	Shell
Saskatchewan	Imperial McCarty Coleman	No. 16-23 Val Marie	LSD 10, Sec. 23, T4, R13, W3M	5,397	United Geo.	1953	Imperial Oil
Saskatchewan	Imperial Tidewater	No. 5-20 Chambery Crown	LSD 5, Sec. 20, T5, R18, W3M	5,300	United Geo.	1953	Imperial Oil
Saskatchewan	Socony Western Prairie	No. 1 Olga	LSD 11, Sec. 25, T5, R23, W3M	5,356	Geocraft	1952	Socony
Saskatchewan	Socony Sohio	No. 15-7 Beaver Valley	LSD 7, Sec. 15, T6, R16, W3M	4,800	GSI	1954	Socony
Saskatchewan	Tidewater	No. 1 Estand Crown	LSD 15, Sec. 11, T6, R20, W3M	7,458	Seismograph	1952	Tidewater
Saskatchewan	Socony Western Prairie	No. 1 Ravenscrag	LSD 2, Sec. 18, T6, R23, W3M	5,033	GSI	1952	Socony
Saskatchewan	Shell	No. 3 Wood Mountain	LSD 7, Sec. 34, T9, R11, W3M	4,778	General Geo.	1954	Shell
Saskatchewan	Shell	No. 17 Wood Mountain	LSD 13, Sec. 28, T7, R9, W3M	4,028	SSX	1954	Shell
Saskatchewan	Imperial Tidewater	No. 6-34 Driscol Crown	LSD 6, Sec. 34, T7, R13, W3M	5,112	GSI	1953	Imperial
Saskatchewan	Socony Woodley Southern	No. 4-9 South Fork	LSD 9, Sec. 4, T7, R21, W3M	4,346	GSI	1954	Socony
Saskatchewan	Husky Phillips	No. 1 Adams Creek	LSD 4, Sec. 4, T7, R28, W3M	5,085	Borg Geo.	1950	
Saskatchewan	Quintana Oils	No. 1 Melavale	LSD 2, Sec. 14, T8, R4, W3M				
Saskatchewan	Shell Oil	No. 1 Wood Mountain	LSD 7, Sec. 34, T9, R11, W3M	7,204	Petty Geo.	1952	Shell
Saskatchewan	Imperial Tidewater	No. 4-1 Admiral	LSD 4, Sec. 1, T9, R16, W3M	4,823	United Geo.	1953	Imperial
Saskatchewan	Socony Western Prairie	No. 22-10B Instow	LSD 10, Sec. 22, T10, R17, W3M	5,325	GSI	1952	Socony
Saskatchewan	Albercan Oil Corp.	No. 1 McCoy Creek	LSD 13, Sec. 33, T10, R28, W3M				Socony
Saskatchewan	Socony Woodley Southern	No. 10-3 Simmie	LSD 13, Sec. 10, T11, R16, W3M	5,128	GSI	1953	Socony Vacuum
Saskatchewan	Socony	No. 10-11B Skibbereen	LSD 15, Sec. 10, T11, R24, W3M	4,365	GSI	1953	Socony Vacuum
Saskatchewan	Tidewater	No. 1 Johnstone Lake Cr.	LSD 9, Sec. 20, T12, R2, W3M	6,010	Petty Geo.	1951	Tidewater
Saskatchewan	Anglo American Gridoil	No. 1 Crane Lake	LSD 13, Sec. 26, T12, R23, W3M				
Saskatchewan	Amurex-Albercan	No. 1-4 Russell	LSD 4, Sec. 34, T12, R25, W3M				
Saskatchewan	Amurex Can. Southern	No. 1-13 Ferguson	LSD 13, Sec. 12, T12, R28, W3M	3,660	GSI	1953	Amurex
Saskatchewan	Norcanols Oil & Gas	No. 1 Swift Current	LSD 11, Sec. 20, T13, R13, W3M	7,890	Carter Oil Co.	1945	Imperial Oil
Saskatchewan	Socony Western Prairie	No. 35-16B Covington	LSD 16, Sec. 35, T13, R17, W3M	3,735	GSI	1952	Socony Vacuum
Saskatchewan	Anglo American Gridoil	No. 1 Gull Lake	LSD 4, Sec. 2, T13, R19, W3M	4,331	GSI		Socony Vacuum
Saskatchewan	Socony Western Prairie	No. 1 Tompkins	LSD 14, Sec. 19, T13, R20, W3M	6,472	GSI	1951	Socony Vacuum
Saskatchewan	Socony Vacuum W. Prairie	No. 6-10B SE. Midway	LSD 10, Sec. 6, T14, R19, W3M	3,764	GSI	1952	Socony Vacuum
Saskatchewan	Socony Western Prairie	No. 12-10B Northeast Midway	LSD 10, Sec. 12, T15, R20, W3M	3,930	GSI	1952	Socony Vacuum
Saskatchewan	Tidewater	No. 1 Morse Crown	LSD 16, Sec. 25, T16, R8, W3M	6,250	GSX	1952	Tidewater
Saskatchewan	Socony Western Prairie	No. 2-14 Contuar	LSD 14, Sec. 2, T16, R17, W3M	4,140	GSI	1952	Socony Vacuum
Saskatchewan	Socony Western Prairie	No. 13-2B Nadeauville	LSD 2, Sec. 13, T16, R21, W3M	4,225	GSI	1952	Socony Vacuum
Saskatchewan	Tidewater	No. 1 Success Crown	LSD 16, Sec. 20, T17, R15, W3M	3,985	United Geo.	1953	Tidewater

County	Company	Lease	Location	Survey Depth	Shot by	Date	Sponsored by
Saskatchewan	Socony Western Prairie	No. 3-6B Success	LSD 6, Sec. 3, T17, R16, W3M	3,948	GSI	1952	Socony Vacuum
Saskatchewan	Socony Woodley Southern	No. 3-7 Success	LSD 7, Sec. 3, T17, R16, W3M	7,403	GSI	1954	Socony Vacuum
Saskatchewan	Socony Woodley Southern	No. 3-7B Success	LSD 7, Sec. 3, T17, R16, W3M				Socony Vacuum
Saskatchewan	Socony Western Prairie	No. 31-6B Wheat Valley	LSD 6, Sec. 31, T17, R17, W3M	3,665	GSI	1952	Socony Vacuum
Saskatchewan	Socony Western Prairie	No. 1 Fosterton	LSD 2, Sec. 10, T17, R18, W3M	3,130	GSI	1952	Socony Vacuum
Saskatchewan	Socony Western Prairie	No. 10-10B Roseray	LSD 10, Sec. 10, T17, R19, W3M	3,885	GSI	1953	Socony Vacuum
Saskatchewan	Socony Woodley Southern	No. 33-3B Bestville	LSD 3, Sec. 33, T17, R22, W3M	3,675	GSI	1953	Socony Vacuum
Saskatchewan	Tidewater	No. 1 Parkbeg Crown	LSD 10, Sec. 32, T18, R3, W3M	6,036	Petty Geo.	1952	Tidewater
Saskatchewan	Imperial Oil Ltd.	No. 1 Imperial Morse	LSD 1, Sec. 6, T18, R7, W3M	6,796	Carter Oil Co.	1945	Imperial
Saskatchewan	Socony Woodley Southern	No. 20-4 Sand Hills	LSD 4, Sec. 20, T18, R24, W3M	2,969	GSI	1953	Socony Vacuum
Saskatchewan	Imperial Calvan	No. 5-21 Fox Valley	LSD 5, Sec. 21, T18, R26, W3M	3,548	GSI	1953	Imperial
Saskatchewan	Tidewater	No. 1 Cabri-Crown	LSD 1, Sec. 23, T20, R19, W3M	3,301	GSX	1952	Tidewater
Saskatchewan	Socony Sohio	No. 13-8 Lancer	LSD 8, Sec. 13, T21, R22, W3M	3,618	GSI	1953	Socony Vacuum
Saskatchewan	Shell Rio Tinto	No. 1 Sceptre	LSD 14, Sec. 31, T21, R23, W3M	3,541	Beaver Geo.	1953	Shell
Saskatchewan	Shell Rio Tinto	No. 2 Sceptre	LSD 5, Sec. 32, T21, R24, W3M	3,340	Discovery Geo.	1953	Shell
Saskatchewan	Tidewater-Imperial	No. 1 Elbow Crown	LSD 1, Sec. 25, T23, R6, W3M	4,000	United Geo.	1953	Tidewater
Saskatchewan	Imperial Tidewater	No. 12-16 Strongfield	LSD 12, Sec. 16, T26, R4, W3M	5,846	United Geo.	1953	Imperial
Saskatchewan	Sohio	No. 1 Wartime	LSD 2, Sec. 14, T26, R17, W3M	5,547	Indep. Exp.	1951	Sohio
Saskatchewan	Husky Phillips	No. 1 Ratonia	LSD 4, Sec. 32, T26, R24, W3M	6,504	GSI	1951	Phillips Petr.
Sasketchewan	Imperial	No. 1 Davidson	LSD 16, Sec. 8, T27, R1, W3M	5,972	Carter Oil Co.	1945	Imperial
Saskatchewan	Tidewater-Imperial	No. 1 Forgan Crown	LSD 4, Sec. 16, T27, R13, W3M	2,800	United Geo.	1952	Tidewater
Saskatchewan	Sohio Standard	No. 1 Fiske	LSD 14, Sec. 21, T29, R18, W3M	5,528	West. Prov.	1951	Sohio
Saskatchewan	Tidewater-Imperial	No. 1 Outlook Crown	LSD 7, Sec. 20, T30, R7, W3M	5,202	United Geo.	1952	Imperial
Saskatchewan	Husky Phillips	No. 1 Kiyiu	LSD 13, Sec. 11, T30, R22, W3M	2,963	United Geo.	1951	Phillips Petr.
Saskatchewan	Tidewater-Imperial	No. 1 Rosetown	LSD 12, Sec. 19, T31, R15, W3M	5,306	United Geo.	1952	Imperial
Saskatchewan	Royalite Albercan	No. 2 Coleville	LSD 5, Sec. 30, T31, R23, W3M				
Saskatchewan	Canada Southern Oils	No. 5-12 Dewer	LSD 5, Sec. 12, T31, R26, W3M	2,410	United Geo.	1954	Canada Southern
Saskatchewan	Tidewater	No. 1 Swanson Crown	LSD 4, Sec. 8, T32, R9, W3M	2,940	United Geo.	1952	Tidewater
Saskatchewan	Canada Southern	No. 1-16 Buffalo Coulee	LSD 1, Sec. 16, T32, R24, W3M				
Saskatchewan	Royalite	No. 1 Ruthilda	LSD 15, Sec. 5, T34, R7, W3M				
Saskatchewan	Albercan Oil Corp.	No. 20-34 Albercan Crown	LSD 1, Sec. 20, T34, R23, W3M	4,021	Indep. Geo.	1950	
Saskatchewan	Tidewater Group	No. 1 Duperow Crown	LSD 4, Sec. 9, T35, R16, W3M	3,945	United Geo.	1950	Tidewater
Saskatchewan	Albercan	No. 22-35 Crown	LSD 2, Sec. 22, T35, R26, W3M				
Saskatchewan	Albercan	No. 1 Castlewood	LSD 4, Sec. 12, T36, R16, W3M				
Saskatchewan	Socony Standard	No. 1 Langham	LSD 9, Sec. 18, T30, R7, W3M	3,970	West Prov.	1951	Socony
Saskatchewan	W. Potash New Superior	No. 1 Bata	LSD 5, Sec. 27, T40, R23, W3M				
Saskatchewan	Can. Southern Albercan	No. 1 Craigmore	LSD 13, Sec. 4, T44, R9, W3M				
Saskatchewan	Britalta	No. 1 Cabin	LSD 16, Sec. 26, T47, R2, W3M	2,480	NW Seismic	1953	Britalta Petr.

ITALY

Abruzzi e Molise	Montecatini	No. 1 Chieti	Lat. 42°17′18″N, Long. 1°41′07″E Rome	2,514M	WGC	1955	
Calabria	Montecatini	No. 1 Scandale	Lat. 39°07′49″N, Long. 4°30′52″E Rome	2,339M	WGC	1952	
Emilia	AGIP	No. 29 Cortemaggiore	Lat. 44°50′19″N, Long. 2°29′10″W Rome	3,950M	WGC?		
Emilia	AGIP	No. 1 Albareto	Lat. 44°40′00″N, Long. 1°41′10″W Rome	2,705M	WGC?		
Emilia	AGIP	No. 4 Ravenna	Lat. 44°26′20″N, Long. 0°13′55″W Rome	2,225M	WGC?		
Emilia	AGIP	No. 5 Imola	Lat. 44°21′30″N, Long. 0°15′00″W Rome	2,295M	WGC?		
Emilia	AGIP	No. 1 Alfonsine	Lat. 44°31′10″N, Long. 0°24′15″W Rome	1,795M	WGC?		
Emilia	AGIP	No. 2 Alfonsine	Lat. 44°31′50″N, Long. 0°26′35″W Rome	1,650M	WGC?		
Emilia	AGIP	No. 3 Alfonsine	Lat. 44°30′50″N, Long. 0°22′35″W Rome	2,490M	WGC?		
Emilia	AGIP	No. 11 Correggio	Lat. 44°41′30″N, Long. 1°41′14″W Rome	1,155M	WGC?		
Emilia	AGIP	No. 1 Camposanto	Lat. 44°46′25″N, Long. 1°19′35″W Rome	2,475M	WGC?		
Emilia	?	No. 6 Cortemaggiore	Lat. 44°50′25″N, Long. 2°31′05″W Rome	2,475M	WGC?		
Emilia	AGIP	Budrio	Lat. 44°34′15″N, Long. 0°52′15″W Rome	Approximate	WGC?	1955?	
Lombardia	AGIP	No. 1 Romanengo	Lat. 45°21′00″N, Long. 2°41′10″W Rome	2,000M	WGC?	1954?	
Lombardia	AGIP	No. 6 Piadena	Lat. 45°07′00″N, Long. 2°10′00″W Rome	3,120M	WGC?	1954?	
Lombardia	AGIP	No. 1 Cremona Nord	Lat. 45°11′40″N, Long. 2°25′25″W Rome	1,950M	WGC?		
Lombardia	AGIP	No. 8 Bordolano	Lat. 45°18′25″N, Long. 2°20′25″W Rome	2,130M	WGC?		
Lombardia	AGIP	No. 1 Soresina	Lat. 45°18′20″N, Long. 2°34′40″W Rome	1,940M	WGC?		
Lombardia	AGIP	Canizano	Lat. 45°25′00″N, Long. 2°38′00″W Rome	Approximate	WGC?	1955?	
Piemonte	AGIP	No. 1 Desana	Lat. 45°18′00″N, Long. 1°10′20″W Rome	3,160M	WGC?	1954?	
Piemonte	AGIP	Argonate	Lat. 45°24′50″N, Long. 1°47′40″W Rome		WGC?	1955?	

County	Company	Lease	Location	Survey Depth		Shot by	Date	Sponsored by
			MEXICO					
Nuevo Leon	Pemex	No. 1 Parorana	15 km S, 78°W of Reynosa	2,885	M	GSI	1952	Pemex
Nuevo Leon	Pemex	No. 1 Cabeza	80 km S, 36°W of Reynosa	3,000	M	GSI	1954	Pemex
Nuevo Leon	Pemex	No. 1 Zacate	50 km S, 62°W of Reynosa	3,002.5	M	GSI	1953	Pemex
Tamaulipas	Pemex	No. 1 Pemex Asturias	23 km S, 35°W of Reynosa	3,000	M	GSI	1952	Pemex
Tamaulipas	Pemex	No. 1 Pemex Delicias	50 km S, 21°W of Reynosa	2,739	M	GSI	1952	Pemex
Tamaulipas	Pemex	No. 1 Jabali	33 km S, 65°W of Reynosa	2,976	M	GSI	1952	Pemex
Tamaulipas	Pemex	No. 2 Mexicano	11 km S, 70°E of Reynosa	2,853.5	M	GSI	1952	Pemex
Tamaulipas	Pemex	No. 3 Pozo Monterrey	25 km S of Reynosa	1,941.6	M	GSI	1950	Pemex
Tamaulipas	Pemex	No. 1 Petr. Mexicanos Becerro	60 km S, 30°W of Reynosa	3,715	M	GSI	1951	Pemex
Tamaulipas	Pemex	No. 1 Pemex Pozo Arguellena	65 km SE of Reynosa	2,500	M	GSI	1952	Pemex
Tamaulipas	Pemex	No. 1 San Rafael	6 km NE of San Rafael	1,840	M	GSI	1949	Pemex
Veracruz	Pemex	No. 1 El Tule	43 km S, 24°E of Reynosa	3,000	M	GSI	1952	Pemex
Veracruz	Pemex	No. 18 Presidente Aleman	6 km S of Papantla	2,491	M	GSI	1952	Pemex
Veracruz	Pemex	No. 2 Arroyo Grande	13 km NE of Papantla	1,708.9	M	GSI	1951	Pemex
Veracruz	Pemex	No. 1 Pozo Verde	15 km NE of Papantla	2,025	M	GSI	1952	Pemex
Veracruz	Pemex	No. 1 Sta. Maria Ixcatepec	Hda. Sta. N175,350 E63,510	2,385	M	GSI	1948	Pemex
Veracruz	Pemex	No. 17 Presidente Aleman	3 km S of Papantla	2,642	M	GSI	1951	Pemex
Veracruz	Pemex	No. 1 San Juan	4½ km? Tres Valles	720	M	GSI	1953	Pemex
Veracruz	Pemex	No. 100 Pozo Rica	1 km N of Petro Mex.	2,551.4	M	GSI	1952	Pemex
Veracruz	Pemex	No. 1 Allende	4 km SE of Tecolutla R. Ferry Crag.	2,470	M	GSI	1954	Pemex
Veracruz	Pemex	No. 1 Las Yaguas	2 km SE of Village Hato Quemado	1,030	M	GSI	1954	Pemex
Veracruz	Pemex	No. 1 San Pablo	4 km SE of Los Naranjos	2,082	M	GSI	1954	Pemex
Veracruz	Pemex	No. 2 San Pablo	3 km E Los Naranjos	2,109	M	GSI	1955	Pemex
Veracruz	Pemex	No. 1 El Chote	8 km SW Papantla	2,675.5	M	GSI	1955	Pemex
			PERSIAN GULF					
	?	No. 9 Fasht Adhom	Lat. 26°06′N, Long. 50°45.25′E	3,610		GSI	1955	Bahrain Pet. Co. Ltd.
			PORTUGUESE WEST AFRICA					
Angola	Purfina	No. 1 Santiago	Lat. 8°30′32″S, Long. 13°24′23″E	1,525		GSI		
Angola	Purfina	No. 2 Cacoba	Lat. 9°19′47″(4)S, Long. 13°40′57″(2)E	1,349		GSI	1953	Purfina
Angola	Purfina	No. 1 Cacoba	Lat. 9°20′45″(0)S, Long. 13°41′56″(4)E	1,527		GSI	1954	Purfina
							1954	Purfina
			SPAIN					
Navarro	?	No. 1 Sondeo Marcilla (Falces Anticline)	?	1,000		GSI	1953	Com. Investigation Petr. Valdebro
			VENEZUELA					
Anzoátegui	Socony-Vacuum	No. 54 WGV	Dist. of Freites N.173,827 E.557,343	7,390		S. S. C.	1948	Socony-Vacuum
Anzoátegui	Socony-Vacuum	No. 1 Cantaura	Dist. of Freites N.204,478 E.533,831	11,958		S. S. C.	1952	Socony-Vacuum
Anzoátegui	Socony-Vacuum	No. 1 N. Oscurote	Dist. of Freites N.189,542 E.585,896	11,050		S. S. C.	1953	Socony-Vacuum
Anzoátegui	Socony-Vacuum	No. 2R La Ceibita	Dist. of Freites N.202,316 E.548,102	10,587		S. S. C.	1953	Socony-Vacuum
Barinas	Socony-Vacuum	No. 1 Silvestre	Dist. of Barinas N.111,204 W.85,956	7,900		S. S. C.	1945	Socony-Vacuum
Barinas	Socony-Vacuum	No. 3 Silvestre	Dist. of Barinas N.104,660 W.91,120	9,869		S. S. C.	1948	Socony-Vacuum
Barinas	Socony-Vacuum	No. 1 Calzada	Dist. of Barinas N.68,385 W.104,603	10,940		S. S. C.	1947	Socony-Vacuum
Barinas	Socony-Vacuum	No. 1 Yaure	Dist. of Barinas N.28,113 W.218,298	8,950		S. S. C.	1946	Socony-Vacuum
Guarico	Socony-Vacuum	No. 1 Silvan	Dist. of Barinas N.111,996 W.95,508	10,940		S. S. C.	1949	Socony-Vacuum
Guarico	Socony-Vacuum	No. 1 Pascua	Dist. of Zaraza N.205,115 E.349,865	7,200		S. S. C.	1947	Socony-Vacuum
Guarico	Socony-Vacuum	No. 1 Pericocal	Dist. of Zaraza N.137,242 E.416,052	5,300		S. S. C.	1944	Socony-Vacuum
Monagas	Socony-Vacuum	No. 6 E. Ruiz	Dist. of Ribas N.181,154 E.365,823	4,646		S. S. C.	1953	Socony-Vacuum
		No. 6 A.X	Dist. of Cedeño N.267,170 E.616,914	8,400		S. S. C.	1947	Socony-Vacuum

County	Company	Lease	Location	Survey Depth	Shot by	Date	Sponsored by
			REVISIONS & CORRECTIONS				
			(corrections are in italics)				
			STATE OF CALIFORNIA				
Kern	Ohio	No. D-1 TIT	SW SW SW Sec. 21, 11N-19W	6,500	*UGC*	*1937*	*CWVSG*
Kern	General Petroleum	No. 8-27 Kernsummer	NE SW SW Sec. 27, 30S -28E	*7,791*	WGC	1945	CWVSG
Kern	Amerada	No. 27-14 Waglay	NE NE SE Sec. 14, 29S -29E	*4,500*	UGC	1946	CWVSG
Kern	Union	No. 85-34 KCL	NW Sec. 34, 28S -25E	*11,240*	WGC	*1937*	CWVSG
Solano	Amerada	No. 1 Comber	Sec. 19, 6N- 2E	*6,441*	Amerada	1945	CWVSG
Tulare	Pacific Western	No. 1B-1 Brunner	Sec. 16, 24S -25E	*7,430*	WGC	1947	CWVSG
			CANADA				
Saskatchewan	Norcanols Oil & Gas	No. 1 Radville	16-36- 5-19-W2M	*7,958*	Carter	1949	*Imperial*
Saskatchewan	Norcanols Oil & Gas	No. 1 Parry	16, 8- 9-21-W2M	*9,042*	Carter	1943	*Imperial*
Saskatchewan	Norcanols-Imperial	No. 1 Dahinda	10-23-10-23-W2M	*5,208*	Carter	1943	*Imperial*
			STATE OF COLORADO				
Logan	Deep Rock	No. 1 State	SW *SE NW* Sec. 1, 9N-49W	4,535	SSC	1951	
			STATE OF NEW MEXICO				
San Juan	Texas	No. 1 Navajo	Sec. 34, *31N*-17W	8,145	Century	1952	*Conoco*
			STATE OF OKLAHOMA				
Cleveland	Hall-Briscoe	No. 1 Crockett	C SW NW Sec. 33, 6N- 1E	6,510	SSC	1942	*Phillips*
			STATE OF TEXAS				
Bastrop	Amerada	No. 1 P. Dolgener	Jesse Holderman A-190	*6,780*	Petty	1951	*SSWSA*
Cameron	Shell	No. 1 Paul Hulsey	San Benito Land & Water S/D	10,600	Shell	1952	*SSWSA*
Cass	Shell	No. 1 Smith	R. Peters Survey A-831	10,700	Petty	1948	*SSWSA*
Chambers	Sun	No. 1 Brandt	Henry Barker Survey	12,105	Petty	*1950*	*Shell*
Coke	Sun	No. 1 W. I. Tubb	660' from N & E Lines—Sec. 253	6,476	KVI	1947	*KVI*
DeWitt	Sterling & *Fox*	No. 1 Hamilton Lost Creek Ranch	A. Lockhart Survey, A-24	10,000	*Petty*	1951	SSWSA
Fayette	Sohio	No. 1 N. W. Brown Est.	Jacob Stiffler Surv. A-287	*7,873*	Shell	1951	SSWSA
Gonzales	Producers Corp. of Nev.	No. 1 E. S. Austin	J. A. Winn Survey *A-465*	6,235	*Petty*	1950	SSWSA
Gregg	Warren	No. 1 Henderson Unit	David Hill Surv. A-93	7,400	Shell	*1951*	SSWSA
Hardin	Shell	No. 1 Kirby Lumber Corp. Tr. 112-A	H&TC RR Surv., A-324	8,950	Shell	1952	*SSWSA*
Hill	J. A. Humphrey et al	No. 1 J. E. Osborne	E. S. Cabler Survey	*8,247*	Shell	1953	Shell
Jefferson	Magnolia	No. 1 Herbert Trust	Sec. 285, T&NO Surv.	11,500	GSI	*1951*	SSWSA
Lavaca	Shell	No. 1 Steinman-King	HT&B RR Surv., A-245	8,777	*Petty*	1950	SSWSA
McMullen	Gulf	No. 1D Shiner Ranch	Jose Alderete Surv. #14, A-842	8,998	Petty	1948	*SSWSA*
Milam	SOT	No. 1 Smith	F. Ruiz Survey	*SOT does not have Velocity survey in this well.*			
Navarro	Brown & Wheeler	No. 1 M. Henderson	Daniel F. Dunham Surv., A-242	7,200	Shell	*1951*	Shell
Newton	Humble	No. 1 Bleakwood Gas Unit	M. B. Lewis Survey, A-265	11,480	*GSI*	1952	SSWSA
Nueces	Glasscock	No. 1 H. W. LaRochelle	Andres de la Fuente, A-111	10,135	*Petty*	1950	SSWSA
Rains	Shell et al.	No. 1 F. D. Prince et al.	James Forsyth Surv., A-80	13,300	Petty & Shell	1952	*SSWSA*
Shelby	American Republic Corp.	No. 1 Jack McLeroy	Stephen English Survey, A-180	6,873	Petty	1950	SSWSA
Wharton	Magnolia	No. 1 Carl Reynolds	Joseph Newman Surv., A-48	14,880	States & IXC	1952	*Shell & Magnolia*
Williamson	F. W. Carr	No. 1 Maggie Mather	Wm. Campbell Surv., A-984	7,015	*Petty*	1951	SSWSA
			VENEZUELA				
Barinas	Socony-Vacuum	No. 1 San Vicente	Dist. of Barinas N. 61,767 W. 32,902	*7,025*	*SSC*	*1941*	*Socony-Vacuum*
Monagas	Socony-Vacuum	No. 1 Soledad	Dist. of Maturin *N. 108,482 E. 698,165*	9,553	SSC	1943	Socony-Vacuum
Monagas	Socony-Vacuum	A. X-1	Dist. of Cedeno *N. 260,542 E. 610,355*	5,020	SSC	1946	*Socony Vacuum*

GEOPHYSICS, VOL. XXI, NO. 1 (JANUARY, 1956), PP. 179–191, 8 FIGS.

GEOPHYSICAL ACTIVITY IN 1955

Interim Report to Midyear*

SIGMUND HAMMER†

I. THE PETROLEUM INDUSTRY

Geophysical activity in explorations for petroleum on a global scale during the first six months of 1955 recorded a 5% increase in rate compared to the total for the previous year. This reverses the downward trend in 1954. However, the rate of geophysical activity so far in 1955 is 1.9% short of equalling the all-time record high of 1953.

The world-wide exploratory effort during the first half of 1955 utilized the average full-time services of 1,084 geophysical crews of all kinds. This is an increase of 48 crews compared to the 1,036 crew total which operated in 1954.

The statistics in the present report represent geophysical activities during the first half of 1955. Comparisons with previous annual statistics, which are made throughout the report, are based on the assumption that the reported rates of activity in the first six months of 1955 will continue for the rest of the year. No seasonal adjustments have been made.

The global distribution of geophysical activities during the first six months of 1955, by area and by method, and rate comparisons with the whole-year statistics for 1954 are given in Table I. Reducing the crew-months statistics to crew-years, we find that the global effort during the first half of 1955 utilized the average full-time operations of various kinds of geophysical crews as follows: seismic 893, gravity 161, magnetic (both airborne and ground) 18, others 12. The changes compared to 1954 on a world-wide basis were: seismic, up 31; gravity, up 23; magnetic, down 2; other, down 4.

In the United States and Canada, the average full-time number of seismic crews totaled 714, up 14. Gravity crews totaled 107, up 15. Magnetic crews averaged 6, down 4.

Major increases in geophysical activity were made in the eastern hemisphere which rose 22%. This great apparent increase may reflect, in part, suspected incompleteness of the 1954 reports to the committee. The United States scored a 4% increase. Canada was down 3%. The western hemisphere as a whole was up 2%. Classified by methods, the greatest percentage increase of activity was in gravity surveying which globally rose 16%. Seismic activity increased 14% in

* Report of the Standing Committee on Geophysical Activity of the Society of Exploration Geophysicists. The members of the committee are: Kenneth L. Cook, Herbert Hoover, Jr., C. C. Lister, Walter S. Olson, Kumiji Iida, A. Garcia Rojas, and Sigmund Hammer, Chairman.

Presented at the 25th Annual Convention of the Society in Denver, Colorado, Oct. 4, 1955.

† Gulf Research & Development Company, Pittsburgh, Pennsylvania.

TABLE I

CREW-MONTHS OF GEOPHYSICAL EXPLORATION FOR PETROLEUM
1955 DATA ARE FOR FIRST SIX MONTHS ONLY

Method	U.S.A.			Canada			Western Hemisphere			Eastern Hemisphere			World		
	1954	1955	Change in Rate	1954	1955	Change in Rate	1954	1955	Change in Rate	1954	1955	Change in Rate	1954	1955	Change in Rate
Seismic	6,863	3,536	+ 3%	1,535	746	− 3%	9,209	4,711	+ 2%	1,130	645	+14%	10,339	5,356	+ 4%
Gravity	997	587	+18	108	54	0	1,302	760	+17	357	205	+15	1,659	965	+16
Magnetic	109	34	−38	9	0	−100	158	53	−33	71	57	+61**	238	110	− 8
Other	—	—	—	—	—	—	162	7	−91**	35	65	+271**	197	72	−27
Total	7,969	4,157	+ 4%	1,652	800	− 3%	10,831	5,531	+ 2%	1,593	972	+22%	12,433	6,503	+ 5%

** Suspected incompleteness of reports suggests these large changes are questionable.

the eastern hemisphere and recorded moderate rises in all other areas except western Canada where a 3% decrease was indicated. Magnetic activity decreased 8% globally. A great percentage increase in the use of this method in the eastern hemisphere did not overcome substantial drops in the western hemisphere. No magnetic surveying in petroleum exploration was reported in Canada.

The month-by-month fluctuations of seismograph and gravity operations in the United States during the past decade are shown in Figure 1. Seismic operations show a definite upward trend during 1955. This reverses the downward trend which characterized the two previous years. A total of 609 seismic crews were operating in the United States at midyear. This is an increase of 81 crews since the low of 528 crews in November, 1954, but is still far below the peak number of 710 crews which were in operation in October, 1952. Gravity operations in the United States up to midyear 1955 continued at a relatively uniform rate.

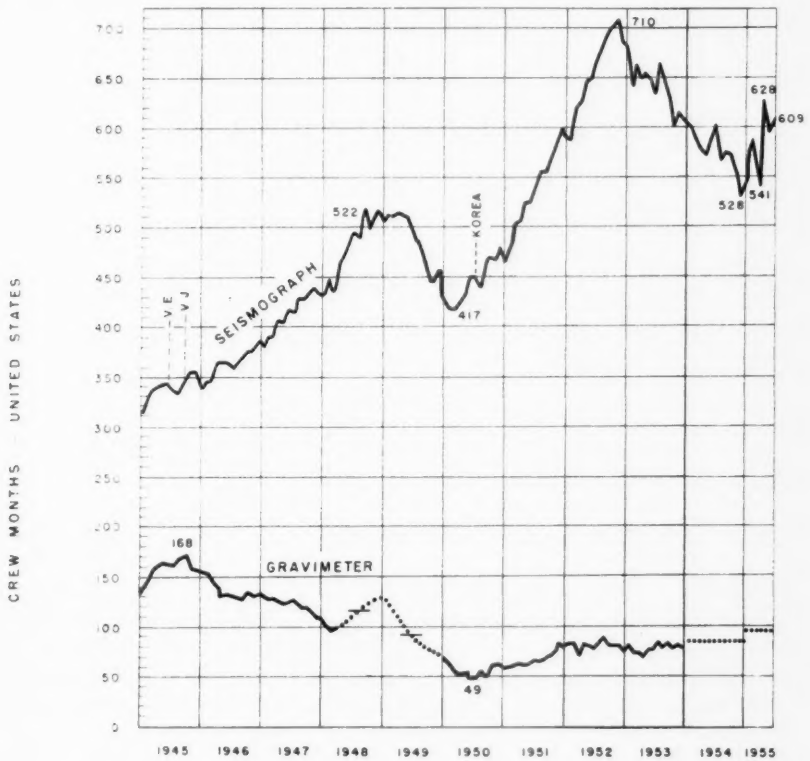

FIG. 1. Monthly variations in seismograph and gravimeter crew-months in the U.S.A.

The number of gravity crews in operation during the six-month period averaged 98, 18% higher than in 1954.

The month-by-month variations of seismic and gravity crews in Canada, back to 1947, are shown in Figure 2. Considerable fluctuation in activity is apparent during the first half of 1955 in both gravity and seismic methods. The number of seismic crews ranged from a high of 150 in March to a low of 100 in April. This

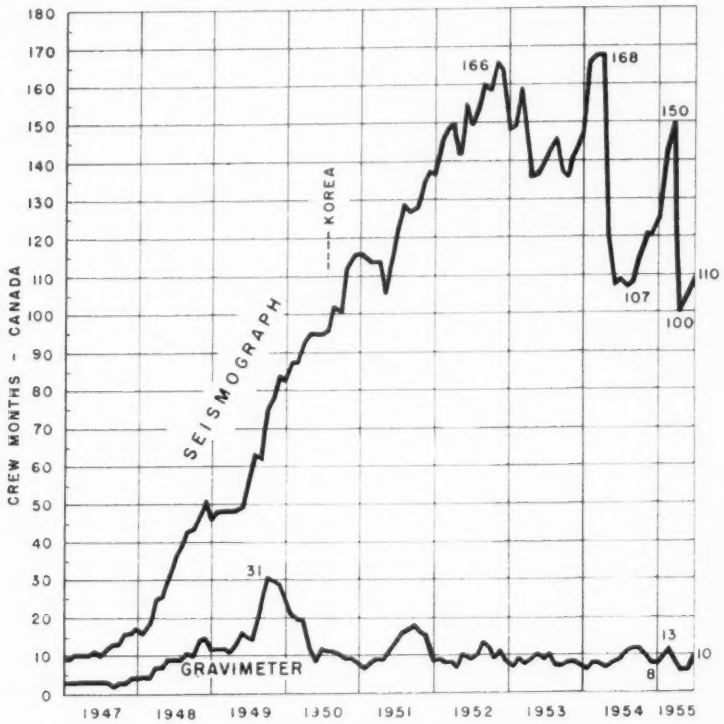

FIG. 2. Monthly variations in seismograph and gravimeter crew-months in Canada.

fluctuation is largely seasonal and reflects differences in mobility of the field crews on the frozen muskeg in winter and during road bans when the frost goes out in the spring. The number of seismic crews operating in Canada during the first half of 1955 averaged 124, down 4, compared to 1954. At midyear 110 seismic crews were active. Gravity crews ranged from 6 to 13 with an average of 9 during the first six months of 1955. A total of 10 gravity crews were reported active in Canada at midyear.

The geographic distribution of seismic operations in the United States during

the first half of 1955 is shown in Figure 3. Changes in relative concentration of effort in various areas are indicated on this chart and also on Figures 4, 5, and 6 by (+) or (−) signs showing increase or decrease compared to 1954. Texas and Louisiana, as for several years past, continue to dominate the chart. These two states together accounted for 55.5%, more than half, of all seismic activity in the United States. The outstanding shift of activity was into coastal Texas (including the Texas portion of the Gulf of Mexico) where the intensity of seismic exploration more than doubled compared to 1954. Coastal Louisiana (including the

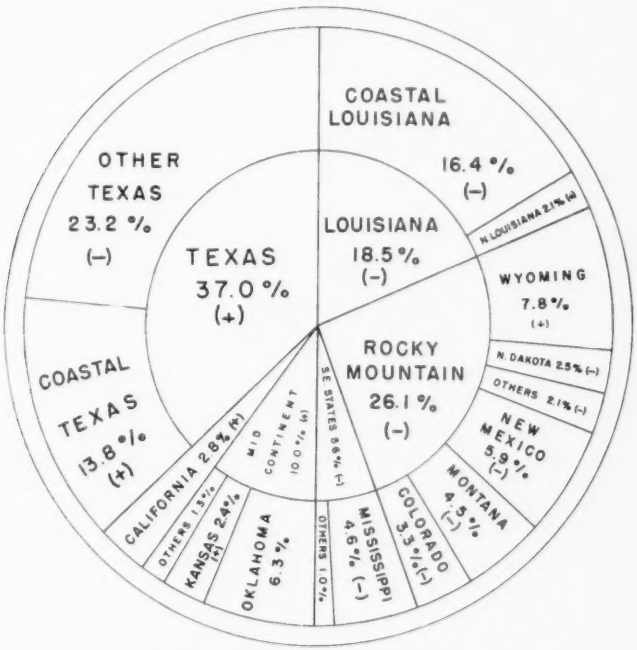

FIG. 3. Distribution of seismic prospecting in U.S.A. in first six months of 1955.

Louisiana portion of the Gulf of Mexico) recorded a 2.1% decrease. Considerable seismic effort was continued in the Rocky Mountain states although at a slightly lower rate than in 1954. The mid-continental states marked a moderate increase, due mainly to augmented seismic activity in Kansas. Moderate decreases in seismic operations were made in Texas, outside the coastal area, and in Montana and North Dakota. Other changes and shifts in seismic explorations in the United States are listed in Table II.

Table II, as well as Table III below, for the first time gives a breakdown of

TABLE II

SEISMOGRAPH CREW-MONTHS IN U.S.A.

State	1954	1955 First Six Months			Change in Rate %
		Company	Contract	Total	
Texas	2,107	534	773	1,307	+24
Louisiana	1,303	198	455	653	+ .2
Wyoming	535	136	141	277	+ 4
Oklahoma	441	110	113	223	+ 1
New Mexico	465	126	82	208	−11
Mississippi	233	77	86	163	+40
Montana	456	58	102	160	−30
Colorado	228	48	69	117	+ 3
California	180	27	74	101	+12
North Dakota	284	47	40	87	−39
Kansas	136	42	42	84	+24
Others	495	71	85	156	−37
Total	6,863	1,474	2,062	3,536	+ 3%

work done by company owned and by contract crews. It is of interest to note that 58.3% of the reported work was done by contract seismic crews compared to 41.7% by company owned seismic crews.

The areal distribution of gravimeter work in the United States in the first six months of 1955 is shown in Figure 4. Texas and Louisiana, again as with seismic activity, accounted for more than half of all gravity work in the nation. However, the total percentage (56.7%) was smaller than in 1954 when these two states accounted for only slightly less than two-thirds of the national total of gravity work. The greatest increase in concentration of gravity activity was in the Rocky Mountain area, principally in New Mexico. The only other major shift was in Texas where gravity work decreased 6.0% compared to the average rate in 1954. Other data on gravity explorations are given in Table III.

TABLE III

GRAVITY CREW-MONTHS IN U.S.A.

State	1954	1955 First Six Months			Change in Rate %
		Company	Contract	Total	
Texas	430	123.75	99.5	223.25	+ 2
Louisiana	183	37.5	71.5	109	+ 19
New Mexico	39	14	45.5	59.5	+205
Nevada	80	5	30	35	− 12
California	48	10	24	34	+ 42
Mississippi	39	18.5	11	29.5	+ 51
Wyoming	57	6	23	29	+ 2
Colorado	15	2	12	14	+ 87
Montana	28	—	14	14	0
Others	69	7	31.5	38.5	+ 12
Total	997	223.75	362	585.75	+ 18%

Almost two-thirds of the reported gravity work was done by contract crews. The precise percentages recorded were: contracted gravity crew-months 61.8%, company owned gravity crew-months 38.2%.

The world distribution of seismic explorations for petroleum during the first half of 1955 is shown in Figure 5. North America continues to dominate the chart with 81.9% of the world total of seismic activity. However, significant relative increases were recorded in South America and in the eastern hemisphere. Although the number of seismic crew-months worked actually increased in the

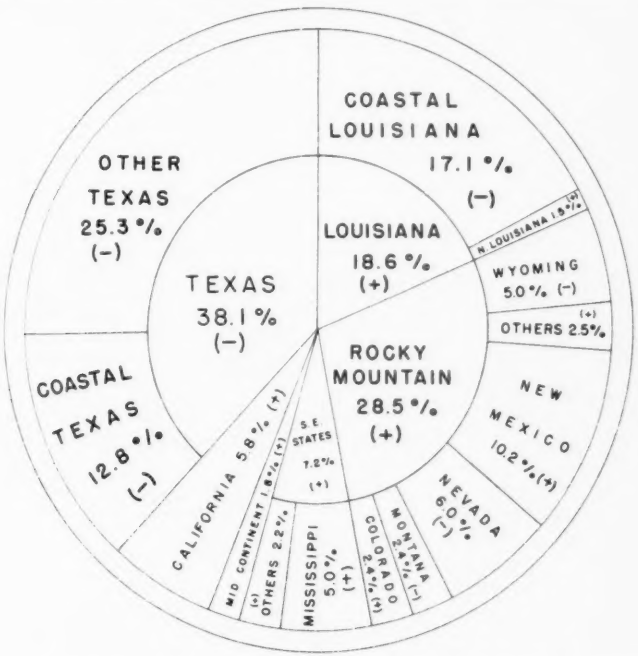
COASTAL LOUISIANA 17.1 % (−)
N. LOUISIANA 1.8 % (0)
WYOMING 5.0 % (−)
(+) OTHERS 2.5 %
NEW MEXICO 10.2 % (+)
NEVADA 6.0 % (−)
MONTANA 2.4 % (−)
COLORADO 2.4 % (+)
MISSISSIPPI 5.0 % (+)
(+) OTHERS 2.2 %
MID CONTINENT 1.8 % (+)
CALIFORNIA 5.8 % (+)
S E STATES 7.2 % (+)
ROCKY MOUNTAIN 28.5 % (+)
LOUISIANA 18.6 % (+)
TEXAS 38.1 % (−)
COASTAL TEXAS 12.8 % (−)
OTHER TEXAS 25.3 % (−)

FIG. 4. Distribution of gravimeter prospecting in U.S.A. in first six months of 1955.

United States and Canada, the relatively larger increases in other parts of the world reduced their percentage participation in the world total. The greatest percentage increase in seismic work took place in Africa although there were no spectacular shifts in seismic activity compared to 1954.

The world distribution of gravimeter explorations for petroleum during the first half of 1955 is shown in Figure 6. More than two-thirds of all gravity activity was concentrated in North America. Substantial increases in relative effort were recorded in Africa and the Middle East. A significant drop was reported in the Far East. Although the level of activity increased over-all, there was a minor

shift of percentage effort in 1955 compared to 1954 from the eastern hemisphere into the western hemisphere.

The reported statistics on magnetic explorations continue to be fragmentary and do not completely differentiate between aeromagnetic and ground magnetic crews. Since these two procedures represent a tremendous difference in effort, both in cost and in coverage, a bare statement of the total number of magnetic crew-months worked does not give a reliable measure of the actual effort by the magnetic method. Taken at face value, the reported statistics in Table I indicate a global decrease in magnetic operations. A substantial increase in magnetic

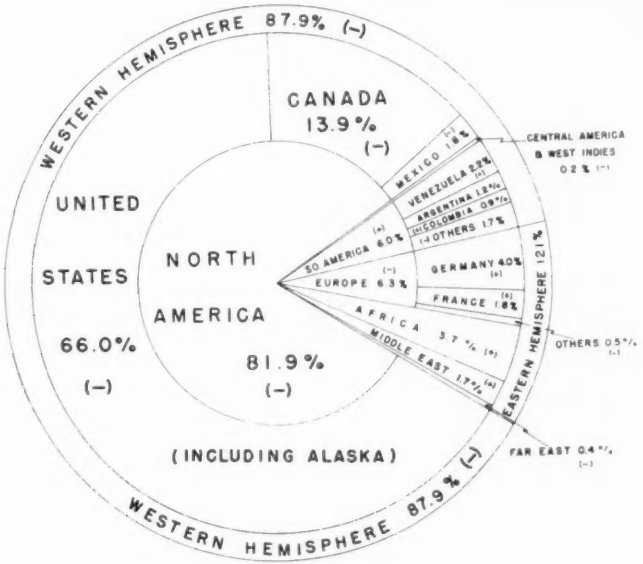

FIG. 5. World distribution of seismograph prospecting in first six months of 1955.

activity was recorded in the eastern hemisphere, but decreases in the United States and Canada were so large that the world-wide total showed a net 8% decrease. The indicated number of magnetic crews employed full-time in petroleum exploration during the first half of 1955 was 6 in the United States and 18 globally.

Cost data reported to the committee on geophysical explorations are incomplete. However, it appears that unit costs were somewhat higher than in 1954. For this reason and also because the level of geophysical activity during the first half of 1955 was higher than in 1954, it is quite certain that investments in geophysical prospecting are now being made at a higher rate than a year ago. If the high level of activity in the first half of the year continues it is probable that

the total capital investment in geophysical exploration for petroleum during 1955 world-wide will be between $350,000,000 and $400,000,000. In the United States the geophysical investment for the year will probably range between $200,000,000 and $250,000,000.

II. THE MINING INDUSTRY

Geophysical explorations in the mining industry rose to new record highs in the first half of 1955. Increases were reported in both total expenditures and in

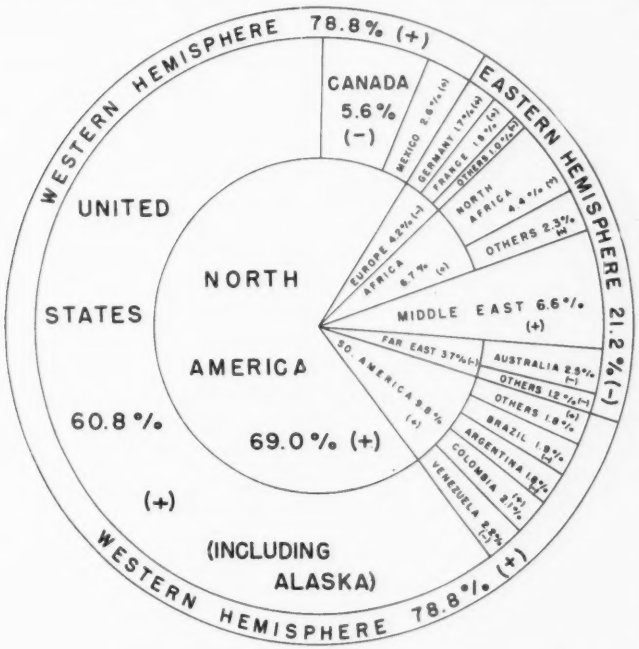

FIG. 6. World distribution of gravimeter prospecting in first six months of 1955.

numbers of professional geophysicists employed in exploration surveys. Research in mining geophysics dropped slightly in number of man-months employed but rose to a new record high in expenditures. Canada continued in the lead with highest capital investments in mining geophysics and also surpassed the United States in number of professional geophysicists employed.

The global investment in mining geophysics during the first six months was at an annual rate of slightly less than $7,000,000 which is nearly a million dollars higher than the investment in 1954. The global employment in terms of professional man-months during the first half of 1955 totaled 3,424, an average full-

time employment of 571 geophysicists. This marked a slight decrease in man-power utilization compared to 1954 when the average number employed was 576. The decrease was due to the drop in the number of men employed in research. As mentioned above, field personnel was higher than a year ago.

Figures 7 and 8 give the data in detail. Two measures of geophysical activity are shown: (a) professional man-months utilized and (b) expenditures converted into United States dollars.

The division of exploratory effort in the various geophysical methods during the first six months of 1955 is given in Figure 7. The magnetic method, including both airborne and ground operations, continued in first place in both number of geophysicists employed and in expenditures. Aeromagnetic operations decreased 50% compared to the average rate in 1954. This decline was almost but not quite offset by large increases in ground magnetic activity. The electromagnetic method, including both airborne and ground operations, recorded a slight decrease in man-power utilization but a very great increase in expenditure and continued in second place in both categories. Arranged in order of decreasing expenditures, the various geophysical methods ranked during the first half of 1955 as follows: (1) magnetic (airborne and ground), (2) electromagnetic (airborne and ground), (3) resistivity and allied methods, (4) miscellaneous methods, mainly Telluric, (5) radioactive (airborne and ground), (6) gravity, (7) geochemical, (8) self-potential and (9) seismic. Arranged in order of decreasing professional man-months utilized the methods ranked in a slightly different order as follows: (1) magnetic (airborne and ground), (2) electromagnetic (airborne and ground), (3) gravity, (4) radioactive (airborne and ground), (5) resistivity and allied methods, (6) miscellaneous methods, (7) geochemical, (8) self-potential, (9) seismic.

Major increases in the applications of mining geophysics were recorded in the first six months of 1955. The electromagnetic method stood highest in the amount of increased investment. Radioactive methods (air and ground) reported the greatest increase in employment. Arranged in terms of declining increase in rate of expenditure, the various methods fall in the following order: (1) electromagnetic, (2) miscellaneous, (3) resistivity and allied methods, (4) radioactive, (5) gravity. Decreased expenditures were recorded for the other methods in the following order: (6) geochemical, (7) self-potential, (8) seismic, (9) magnetic. The order in terms of increase or decrease in man-power utilization differs in a few places but follows essentially the same trend. The greatest percentage increase in both expenditure and man-power, was reported in the use of miscellaneous methods, principally Telluric. The largest percentage decrease in expenditure was recorded for the seismic method.

Research in the applications of all types of geophysical methods to mining exploration problems rose to a new record high in 1955. Reported investments in research during the first half of the year totaled about $850,000 which at an annual rate is up 10.2% compared to 1954. Professional man-months devoted to research showed a slight decline.

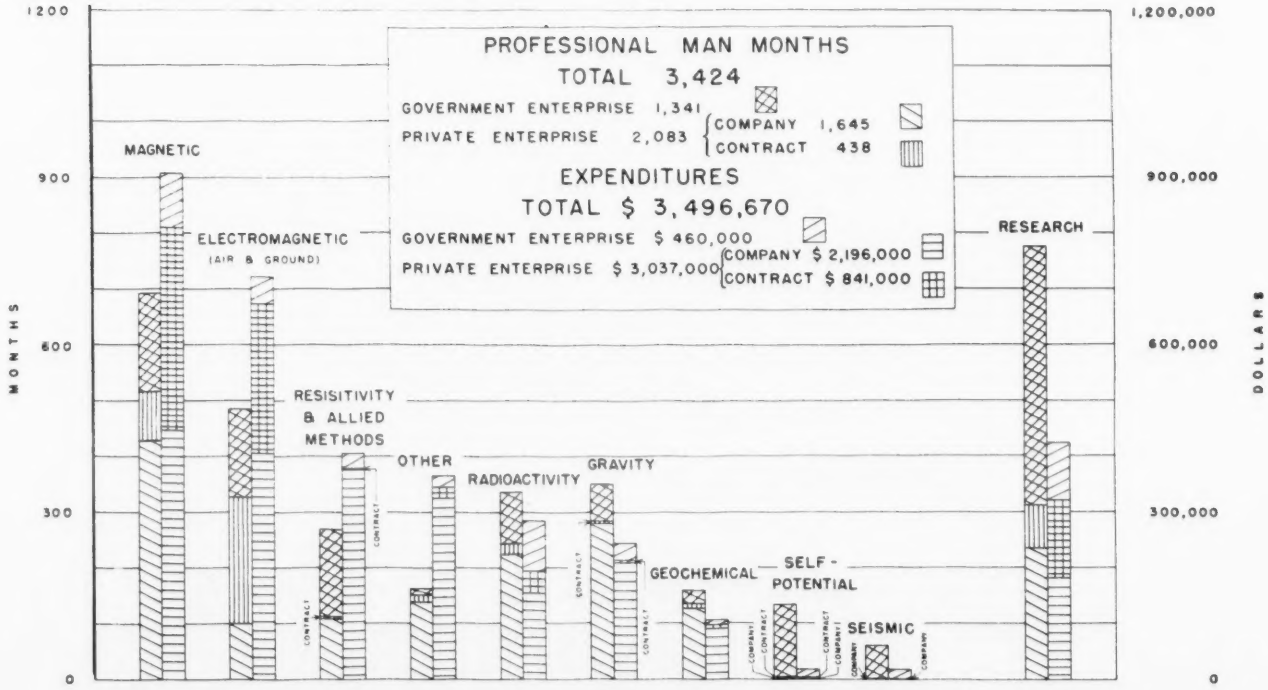

FIG. 7. Mining geophysics—World wide effort in first six months of 1955 by methods.

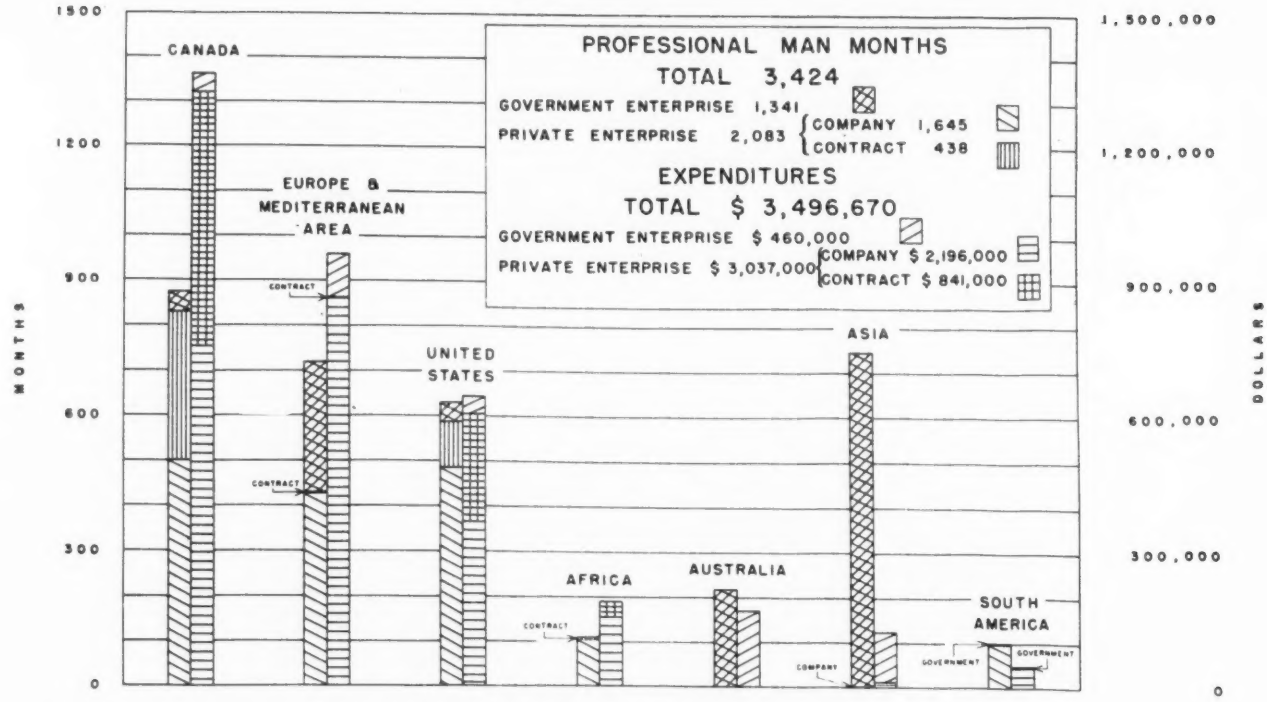

FIG. 8. Mining geophysics—World wide effort in first six months of 1955 by areas.

The utilization of mining geophysics in various areas of the world is shown in Figure 8. Canada stood first in both man-power and expenditure. In expenditures, the various areas ranked as follows: (1) Canada, (2) Europe and Mediterranean area, (3) United States, (4) Africa, (5) Australia, (6) Asia, (7) South America. In terms of utilized professional man-months, the rank was slightly different as follows: (1) Canada, (2) Asia, (3) Europe and Mediterranean area, (4) United States, (5) Australia, (6) Africa, (7) South America.

Increases in activity were reported in Canada, Europe and Mediterranean area, Australia, and South America. Asia reported decreased expenditures but increased man-power utilization. Decreases in activity were recorded in Africa and the United States. The greatest percentage increase in activity compared to 1954 was reported in Australia. The greatest percentage decrease in terms of expenditure was in Asia, in terms of man-months in Africa.

Governmental agencies are relatively active in mining geophysics. Worldwide, the reported government-sponsored investment during the first half of 1955 amounted to nearly a half-million dollars or 13.2% of the total expenditure. In terms of manpower the governmental participation amounted to 39.2%. Private enterprise accounted for 60.8% of employment and 86.8% of expenditures in mining geophysics. These figures represent a continuation of the previous trend away from government operations and increased private enterprise. In privately sponsored explorations, company owned operations accounted for the major share of activity, 79% of man-months and 72% of expenditures. (This is a very different ratio than in Petroleum exploration.) Contracted operations accounted for 21% of man-months and 28% of expenditures for explorations by private enterprise. No government-sponsored activity by contracted effort was reported.

The continuation of the rising trend in the applications of mining geophysics is an encouraging sign of greater growth to follow. Potential expansions of mining geophysics are probably as great now as was the case in the petroleum industry twenty-five years ago. The prospects for the future in mining geophysics are definitely optimistic.

DEPARTMENTS

PATENTS

O. F. RITZMANN*

GEOCHEMICAL PROSPECTING

. S. *No. 2,712,986.* W. B. Huckabay. Iss. 7/12/55. App. 9/8/53. Assign. Socony-Vacuum Oil Co., Inc.

Geochemical Exploration Method. A geochemical prospecting method in which soil samples are analyzed for the concentration of paraffin hydrocarbons and of lipids and the ratio plotted.

U. S. No. 2,713,010. L. F. Bonner, Iss. 7/12/55. App. 10/19/53. Assign. Esso Research and Engineering Co.

Method of Conditioning Hot Wire Gas Detectors. A method of removing combustible deposits from the hot wire of a gas detector used in mud logging in which the detector is periodically flashed with the vapor of a volatile oxygenated organic compound such as aliphatic alcohols, ketones or ether.

U. S. No. 2,715,450. J. E. Bliss and A. J. Joseph. Iss. 8/16/55. App. 10/30/51. Assign. Phillips Petroleum Co.

Degassing of Drilling Mud. Apparatus for detecting small quantities of gas in drilling mud in which a measured quantity of mud is superheated under pressure and then transferred to an evacuated chamber and the released gas mixed with air and analyzed in a combustion unit having a platinum filament in a bridge circuit.

MAGNETIC PROSPECTING

U. S. No. 2,713,661. O. H. Schmitt. Iss. 7/19/55. App. 8/7/44. Assign. U.S.A.

Phase-Shift Magnetometer. A magnetic detector of the phase-shift type whose exciting oscillator also produces a double-frequency reference signal and the detector output is compared with the reference signal by means of a phase discriminator.

U. S. No. 2,714,182. W. H. Hewitt, Jr. Iss. 7/26/55. App. 6/21/52. Assign. Bell Telephone Laboratories, Inc.

Hall Effect Devices. A germanium plate in which linearity of Hall-effect voltage with input voltage and magnetic field is obtained by proper orientation of the geometrical axes of the plate with respect to the crystallographic axes of the mother crystal.

U. S. No. 2,715,198. W. E. Tolles. Iss. 8/9/55. App. 8/14/44. Assign. U.S.A.

Eddy-Current Compensator. A system for compensating eddy currents in a metal surface of an aircraft having a magnetic detector which picks up the flux normal to the surface with its output differentiated, amplified, and applied to a compensating coil.

U. S. No. 2,715,207. O. H. Schmitt. Iss. 8/9/55. App. 8/14/44. Assign. U.S.A.

Wave-Train Detector. A magnetic detector whose output is demodulated to obtain the envelope frequency which is amplified with a tuned amplifier and the resulting signal compared with that of the driving oscillator by a phase-sensitive discriminator.

U. S. No. 2,718,205. R. W. Gebs and B. W. Ridley. Iss. 9/20/55. App. 11/10/52.

* Gulf Oil Corporation, Patent Department.

Degaussing System. A degaussing system having coils to neutralize particular field components fed by amplidyne generators whose reference field is controlled from a resolver which is adjusted by remote control from the ship's compass.

SEISMIC PROSPECTING

U. S. No. 2,713,395. L. M. Swift. Iss. 7/19/55. App. 3/28/51. Assign. Institute of Inventive Research.

Refraction Shooting. An air shooting system for accentuating refraction arrivals using a row of equally elevated shots aligned in the direction of the receivers and fired in time sequence so that the space rate of firing is equal to the seismic velocity in the refraction layer.

U. S. No. 2,713,620. A. E. Tilley. Iss. 7/19/55. App. 4/29/49. Assign. Phillips Petroleum Co.

Automatic Volume Control System. A seismograph avc system using a push-pull amplifier with part of the output rectified, filtered, and applied to variable-impedance devices shunting the control element of both tubes.

U. S. No. 2,714,672. H. D. Wright and E. G. Laue. Iss. 8/2/55. App. 8/30/52. Assign. H. D. Wright.

Accelerometer. A piezoelectric accelerometer having a pair of barium titanate wafers loaded with a mass and enclosed in a compliant cylindrical case.

U. S. No. 2,715,717. J. F. Keithley and M. L. Sands. Iss. 8/16/55. App. 3/25/43.

Method and Apparatus for Measuring and Analyzing Transient Pressures in a Body of Water. Apparatus for measuring pressure waves in water over a wide range of frequencies using a hydrophone with a diaphragm connected to a reluctance-type transducer tuned by a variable condenser and in an a-c bridge circuit whose unbalance is demodulated and recorded for subsequent analysis.

U. S. No. 2,717,368. M. Swan. Iss. 9/6/55. App. 5/18/53. Assign. United Geophysical Corp.

Testing Apparatus. An arrangement of piezoelectric pressure hydrophones and associated preamplifier spaced on a cable for lowering into a well and arranged so that a step voltage test may be made on any desired channel.

U. S. No. 2,717,369. T. Bardeen and R. W. Williams. Iss. 9/6/55. App. 7/31/52. Assign. Gulf Research & Development Co.

Pressure-Sensitive Deep Well Seismograph Detector. A deep-well seismograph detector whose inertia mass is also coupled to a diaphragm in contact with the well fluid and backed by a large rigid chamber filled with a compliant liquid which is pressure equalized by means of a capillary leak, the signal effects due to seismic translation and pressure wave in the well fluid being additive.

U. S. No. 2,717,656. C. E. Bannister. Iss. 9/13/55. App. 10/31/51.

Method and Apparatus for Use in Surveying Earth Formation by Explosion and Seismograph. A seismograph shot-planting method in which the charge is contained in a long tube and transported to location by helicopter, dropped into position, and detonated.

U. S. No. 2,717,821. E. G. Perry, Jr. Iss. 9/13/55. App. 6/21/48. Assign. Texas Instruments Inc.

Seismograph Timing Devices. A synchronous timing-line motor having a flywheel mounted on the rotor shaft with slight friction to prevent hunting and a clutch to engage the rotor in starting.

U. S. No. 2,718,928. O. Weiss. Iss. 9/27/55. App. 3/7/51. Assign. Weiss Geophysical Corp.

Seismic Method of Geological Exploration. A seismic method of locating the edge of a low-velocity layer by firing a shot in a well where it penetrates the low-velocity layer and observing the amplitude of seismic arrivals at detectors on the surface above the edge of the layer.

U. S. No. 2,718,929. O. Weiss. Iss. 9/27/55. App. 6/18/51. Assign. Weiss Geophysical Corp.

Seismic Method of Geological Exploration. A method of locating a high velocity body which intersects a low-velocity layer by placing shot and detector in a well opposite the low-velocity layer and timing reflections from the high-velocity body.

U. S. No. 2,718,930. W. O. Bazhaw. Iss. 9/27/55. App. 7/5/52.

Method of Deep Well Surveying. A method of seismic exploration in which the shot and a spread of detectors are placed in a deep well with crossed spreads of detectors on the surface, reflected events received by the well detectors and refracted events received by the surface detectors being analyzed to locate underground formations.

WELL LOGGING

U. S. No. 2,712,609. G. Herzog, A. H. Lord, Jr. and E. Pancake. Iss. 7/5/55. App. 3/24/50. Assign. The Texas Co.

Surveying by Detection of Radiation. A radioactivity logging system in which the current pulses from the detector are recorded on a magnetic tape which is subsequently played back and re-recorded through apparatus which integrates the pulses under selected time constants.

U. S. No. 2,712,626. H.-G. Doll. Iss. 7/5/55. App. 11/19/48. Assign. Schlumberger Well Surveying Corp.

Selective Spontaneous Potential Well Logging Method and Apparatus. An s-p logging system in which the s-p electrode has two electrodes on each side of it and the current flow from ground to the outer pair of electrodes is continually adjusted so that a constant potential is maintained between ground and the electrodes adjacent the s-p electrode, and the potential measured between the s-p electrode and ground.

U. S. No. 2,712,627. H.-G. Doll. Iss. 7/5/55. App. 5/12/50. Assign. Schlumberger Well Surveying Corp.

Electrical Resistivity Well Logging Method and Apparatus. A formation resistivity logging system in which the principal current electrode in the well has two electrodes on each side of it and the current to the outer electrodes is automatically adjusted so as to maintain zero potential between the principal electrode and the adjacent electrodes.

U. S. No. 2,712,628. H.-G. Doll. Iss. 7/5/55. App. 2/19/51. Assign. Schlumberger Well Surveying Corp.

Electrical Logging Apparatus. A formation resistivity logging system in which the principal current electrode in the well is flanked by elongated electrodes to which current is supplied so as to maintain zero potential between the principal electrode and the flanking electrodes.

U. S. No. 2,712,629. H.-G. Doll. Iss. 7/5/55. App. 3/7/51. Assign. Schlumberger Well Surveying Corp.

Electrical Logging of Earth Formations Traversed by a Bore Hole. A formation resistivity logging system having electrodes pressed against the borehole wall, the principal central electrode being surrounded by concentric electrodes whose current is automatically adjusted to maintain zero potential between the principal electrode and adjacent ones.

U. S. No. 2,712,630. H.-G. Doll. Iss. 7/5/55. App. 11/20/51. Assign. Schlumberger Well Surveying Corp.

Methods and Apparatus for Electrical Logging of Wells. A system for measuring resistivity of the invaded zone in a well having closely-spaced annular electrodes pressed outwardly against the bore-

hole wall, one of the current electrodes having adjacent electrodes whose current is adjusted to maintain zero potential between them and the principal current electrode, and observing potential variations between ground and an electrode adjacent the principal electrode.

U. S. No. 2,712,631. M. C. Ferre. Iss. 7/5/55. App. 4/16/52. Assign. Schlumberger Well Surveying Corp.

Electrical Well Logging. A formation resistivity logging system having a vertical array of electrodes, a central pick-up electrode being flanked by a pair of electrodes between which a current is passed so as to maintain zero potential between the extreme electrodes and ground, the measuring current being passed between ground and electrodes adjacent the pick-up electrode.

U. S. No. 2,712,632. H.-G. Doll. Iss. 7/5/55. App. 11/18/48 and 6/3/53. Assign. Schlumberger Well Surveying Corp.

Electrical Well Logging Method and Apparatus. An s-p logging system in which the potential is measured between a central electrode and parallel auxiliary electrodes above and below it, and a-c is supplied between ground and other electrodes outside the auxiliary electrodes so as to maintain zero potential between the auxiliary electrodes and ground.

U. S. No. 2,712,697. M. P. Lebourg. Iss. 7/12/55. App. 3/30/54. Assign. Schlumberger Well Surveying Corp.

Borehole Gauge. A borehole calipering device having a sealed non-magnetic case and magnets on the caliper arms which move magnets inside the case to change resistance in an electric circuit.

U. S. No. 2,713,146. H.-G. Doll. Iss. 7/12/55. App. 10/18/49, 6/3/53 and 2/16/54. Assign. Schlumberger Well Surveying Corp.

Spontaneous Potential Well Logging Method and Apparatus. An s-p logging system in which the potential is measured between a ground electrode and an electrode pressed against the borehole wall but otherwise insulated from well fluid by an insulating sheath.

U. S. No. 2,713,147. A. A. Stripling. Iss. 7/12/55. App. 6/29/53. Assign. Socony-Vacuum Oil Co., Inc.

Acoustic Velocity-Electrical Resistance Correlation Well Logging. A well logging system in which the acoustic travel time between a source and receiver is measured and used to generate a synthetic resistivity signal which is a power function of the velocity and is related to an assumed normal fluid saturation and depth, and comparing the synthetic curve with the simultaneously measured resistivity to locate formations of abnormal fluid saturation.

U. S. No. 2,714,169. F. C. Armistead. Iss. 7/26/55. App. 12/22/51. Assign. Texaco Development Corp.

Gamma Ray Measuring. A scintillometer for use in well logging using a liquid luminophor which is cooled and circulated about the photomultiplier tube.

U. S. No. 2,716,340. W. T. Nance and C. L. Rabe. Iss. 8/30/55. App. 10/20/52. Assign. Shell Development Co.

Apparatus for Measuring the Volume of a Borehole. A volume logging apparatus having a calipering device in the borehole whose signal is squared and integrated against a depth signal obtained from the cable sheave.

U. S. No. 2,716,730. P. S. Williams. Iss. 8/30/55. App. 7/24/52. Assign. Esso Research and Engineering Co.

Apparatus for Magnetic Well Logging. A magnetic logging apparatus having three vertically-spaced inductor coils on a frame rotated on a vertical axis by a motor, the upper and lower coils

being connected in series to give a differential voltage whose phase and amplitude is compared with the voltage from the middle coil and both voltages and phase recorded.

U. S. No. 2,718,143. H. J. Pankratz. Iss. 9/20/55. App. 10/28/49. Assign. Phillips Petroleum Co.

Method of and Apparatus for Measuring the Diameter of a Well Bore. A method of logging the area of a borehole full of heavy liquid by superimposing an immiscible slightly lighter liquid and an immiscible still lighter liquid so that two interfaces will form, and measuring the distance between the interfaces as pressure is applied to force the lowest liquid into the formation.

U. S. No. 2,718,145. R. G. Nisle. Iss. 9/20/55. App. 9/16/49. Assign. Phillips Petroleum Co.

Surface Indicating Bottom-Hole Pressure Measuring Device. A bottom hole pressure gauge using a spring bellows whose deflection is transmitted to opposite points of a parallelogram linkage which changes the electrical resistance of a coil.

U. S. No. 2,718,449. R. G. Piety and F. L. McMillan, Jr. Iss. 9/20/55. App. 9/23/49. Assign. Phillips Petroleum Co.

Pulse Measuring Apparatus. A system for converting a logging voltage into pulses of varying time spacing so that recording may be done on a facsimile recorder, the original voltage being rectified, filtered and mixed with a saw-tooth wave which is cut off at the level of the measured voltage.

MISCELLANEOUS

U. S. No. 2,713,261. C. J. Butterworth and S. W. Gurasich. Iss. 7/19/55. App. 10/2/51. Assign. Sperry-Sun Well Surveying Co.

Self-Contained Flowmeter. A well flowmeter having an impeller which is magnetically coupled to a speedometer which records on a clock-driven record inside a sealed central housing.

U. S. No. 2,713,682. E. H. Schoenfeld. Iss. 7/19/55. App. 11/29/47. Assign. U. S. A.

Radio Navigation System of Loran Type. A loran navigation system in which A and B signals are transmitted from two ground stations and a c-r tube used to measure the time difference of their arrival by deflecting the c-r beam at a repetitive rate four times that of the A pulses and blocking the c-r beam whenever the received B pulse is phased to appear at the start of the c-r deflection.

U. S. No. 2,713,789. F. C. Kelton. Iss. 7/26/55. App. 10/16/51. Assign. Core Laboratories, Inc.

Permeameter. A core testing apparatus which clamps the core between a pair of semi-cylindrical jaws with ports, and gas is passed from one jaw through the core to the other jaw, the ends of the core being sealed with plastic.

U. S. No. 2,714,680. N. Warmoltz and G. W. Rathenau. Iss. 8/2/55. App. 6/23/50 and 6/13/51. Assign. Hartford National Bank and Trust Co.

Radiation Counter Tube. A radiation counter tube having an ionizable gas containing a halogen and a pair of electrodes coated with chromium sesquioxide.

U. S. No. 2,716,747. E. J. Crossland. Iss. 8/30/55. App. 8/26/53. Assign. Seismograph Service Corp.

Radio Location System. A phase-comparison type of position-determining system in which three spaced transmitters transmit identical frequencies and sequentially also transmit three different frequencies and one of these is used to modulate the identical frequency signals.

U. S. No. 2,716,890. P. W. Martin. Iss. 9/6/55. App. 10/3/49.

Apparatus for Determining Point at which a Pipe is Stuck in a Well. A device for determining motion of pipe when tension is applied or released and having an electromagnet which grips the pipe and a suspended mass whose motion is detected by a reluctance-type transducer whose signal is transmitted to the surface.

U. S. No. 2,717,039. W. R. Gieske. Iss. 9/6/55. App. 9/2/52. Assign. The Ford Alexander Corp.

Detector Device for Exploring Ferromagnetic Structure in Well Bores. A device for detecting pipe breaks in a well and having a soft iron core between like poles of two permanent bar magnets with a coil on the core connected to a recording galvanometer.

U. S. No. 2,717,735. D. G. C. Luck. Iss. 9/13/55. App. 6/30/53. Assign. Radio Corp. of America.

Means for Locating the Position of a Mobile Craft. A radio navigation system using a pair of fixed stations each of which transmits a rotating directional signal and a reference phase signal, the mobile station having its receiver connected to a computer which resolves the signals into rectangular coordinates.

U. S. No. 2,717,760. C. E. Bannister. Iss. 9/13/55. App. 11/8/47, 3/15/52 and 6/3/52.

Apparatus for Taking a Sample of an Earth Formation. A soil sampler or side-wall coring tool in which the sample tube is explosively driven into the formation and a properly timed succeeding explosion in an annular chamber retracts the tube into the tool.

U. S. No. 2,718,002. A. G. Clavier. Iss. 9/13/55. App. 2/2/49. Assign. International Standard Electric Corp.

Long Range Navigation System. A long-range radio navigation system using two fixed stations each of which transmits a carrier wave modulated with the same low frequency whose relative phase is shifted at a known rate together with a reference signal, the mobile receiver beating the two carrier waves and detecting the resulting amplitude modulation and indicating the time interval between an extreme beat and the reference signal.

U. S. No. 2,718,061. A. C. Omberg, C. P. Means and B. H. Ochterbeck. Iss. 9/20/55. App. 10/10/46. Assign. Bendix Aviation Corp.

Automatic Position Plotter. A device for automatically tracking the position of an airplane on a map from polar information of the airplane's position relative to two fixed ground locations and having a coursor which is positioned along rectangular coordinates by servo motors which are controlled by the error voltage between the observed information and two control transformers having radius wires to the coursor.

U. S. No. 2,718,141. L. A. Richards. Iss. 9/20/55. App. 1/25/52.

Electro-Thermal Element for Measuring Moisture in Porous Media. A device for measuring the moisture content of materials and having a heating coil with associated resistance thermometer, the rise in temperature for a given energy input being measured.

U. S. No. 2,718,610. G. H. Krawinkel. Iss. 9/20/55. App. 2/1/51.

Acceleration Indicating System. A cathode ray flight path deviation accelerometer in which the c-r beam is modulated and deflected 90° after traversing a fixed distance, and the spread of the beam detected.

SELECTED LIST OF U. S. PATENTS ISSUED DURING THE THIRD QUARTER OF 1955

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* A key to the subject classification system will be found in GEOPHYSICS, v. 12, pp. 256–264 (April, 1947).

[a] Abstracted on preceding pages of this issue.

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The Planet Earth, *Scientific American*, Vol. 193, No. 3, Sept. 1955.

The *Scientific American* has a tradition of devoting one entire issue each year to a single subject. For the year 1955, in anticipation of the International Geophysical Year to begin in July, 1957, the eleven articles are devoted to the Earth and, therefore, all may be considered as concerned with geophysics in its broader sense.

"The Voyage of the Atka" by Paul A. Humphrey (Meteorologist in the Scientific Services Division of the U. S. Weather Bureau) gives an account of the voyage of an icebreaker to Antarctica, made to review conditions there and to select sites for at least part of the 31 observation stations to be occupied by ten different nations during the International Geophysical Year (IGY). Considerable change was found in the boundaries and condition of the ice, particularly in the Little America area, where a substantial part of the supplies left there in earlier expeditions has been lost from recession of the ice. The scientific work carried out by the expedition included meteorology, oceanography, glaciology, geomagnetism, cosmic rays and ionospheric physics. The article reviews briefly the various observations made and is illustrated with several photographs and with maps showing the route taken by the ship and changes in the little America area.

"The Interior of the Earth" by K. E. Bullen (Professor of Applied Mathematics at the University of Sydney, Australia) reviews the instruments and analysis by which the nature of the interior of the earth is inferred from seismograms. The article is illustrated with a sample seismogram, indicating the onset of different types of waves and by diagrams showing the different shells of the earth and the various types of earthquake trajectories transmitted through them. There are diagrams showing, as a function of depth, wave speeds for longitudinal and transverse waves, density, pressure, rigidity and incompressibility. The article includes some new ideas about the composition of the inner core of the earth, some of which are, at present, highly controversial.

"The Origin of Continents" by Marshall Kay (Professor of Geology at Columbia University) reviews the differences in composition of the crust under continents and oceans in terms of different thicknesses of sial and sima and the variations in depth to the Mohorovicic discontinuity. The examples are all from the North American Continent. A theory is presented which suggests that originally the earth was of rather uniform composition and that the continents began as relatively small islands which were added to by upheavals such as are indicated by the island arcs. Some support for this suggestion is given by a map showing the ages of basement rocks in different parts of North America and indicating that the oldest rocks are in the center of the Canadian Shield (around Hudson Bay) and that the ages decrease more or less regularly away from this center.

"Glaciers" by William O. Field (Head, Department of Exploration and Field Research of the American Geographical Society) reviews the water balance of the earth and the approximately one percent of the water which is tied up in glacial areas which are shown on a world map. The principal advances and retreats of the glaciers and the corresponding climatic changes in historic times are reviewed; they reached a maximum advance in the latter part of the 19th century and have since been shrinking at a rate that would cause sea level to rise about 2.5 inches per century. The IGY program includes several glacial study stations on the Antartic Continent. The article is illustrated by several spectacular photographs of glaciers in mountain areas.

"The Circulation of the Oceans" by Walter Munk, (Professor of Geophysics at the Scripps Institution of Oceanography) reviews the great advances in detailed knowledge of ocean currents which have resulted from studies made with accurate navigation by electronic means (Loran), and by measuring electric potentials induced by water currents moving in the earth's magnetic field. It is found that the Gulf stream, for instance, may vary in its course as much as 100 miles and contains unsuspected details with variations which compare roughly with those of a weather map. The circulation of the oceans is shown on a world map and an explanation is given in terms of the idealized effects of the trade winds and other more or less regular movements of the atmosphere.

"The Earth From Space" reviews very briefly the methods by which high altitude photographs are made from rockets and includes two striking pictures, made from heights of 101 and 143 miles.

"The Circulation of the Atmosphere" by Harry Wexler (Chief of the Scientific Services Division of the U. S. Weather Bureau) first reviews the dependence of life on the movement of the air. Fundamentally, the circulation depends on the fact that in lower latitudes (between 38 degrees north and south), the earth absorbs more solar radiation than it loses and at higher latitudes the reverse is true. The resulting circulation, modified by the rotation of the earth and by topography becomes complicated and is broken into a number of cells which are illustrated by several diagrams. The general pattern of the circulation is fairly well understood and estimates are given of the transport of momentum, energy, and water vapor. During the IGY it is planned to establish several pole to pole chains of weather observation stations along two or three different meridians.

"The Ionosphere" by T. N. Gautier (Chief of Upper Atmosphere Research, Radio Propagation Division, National Bureau of Standards) reviews the discovery of the ionized layer and the work of Kennely and Heaviside. The density of electrons in the ionized layers can be determined from the frequency of radio waves which are reflected. A record is made of reflections as a pulse frequency is changed over a range from one to 25 megacycles. Motions in the ionosphere correspond to electric currents and are related to the daily variations in the earth's magnetic field and several techniques for measuring these motions are reviewed. Since radio transmission is dependent on the ionosphere, a constant check is desirable to determine preferred frequencies for radio communication. During the IGY it is planned to make systematic measurements of ionospheric conditions along three north-south chains of stations and an east-west chain around the world somewhat near the equator.

"Aurora and Airglow" by C. T. Elvey (Director of the Geophysical Institute at the University of Alaska) and Franklin E. Roach (Consultant, Radio Propagation Physics Division, National Bureau of Standards) reviews the evidence that the aurora is caused by streams of charged particles from the sun that are guided by the earth's magnetic field toward the magnetic poles. Studies of the aurora are made with an all-sky camera (which takes a picture of the entire hemisphere by photographing the image in a convex mirror) and by spectroscopy; the latter is difficult because of the low

intensity. From the observations and from laboratory experiments, a fairly clear explanation of the source of the aurora in terms of excitation of certain molecules high in the atmosphere has been worked out. The "airglow" is a subtle light of very low intensity and difficult to study. However, by long exposures, some requiring several nights, the spectra and the atoms from which they come are becoming fairly well known. During the IGY simultaneous maps of the aurora will be made over the earth to correlate activity with that of the sun and with magnetic storms and other phenomena.

"The Earth's Magnetism" by S. K. Runcorn (Assistant Director of Research in the Department of Geodesy and Geophysics at the University of Cambridge) reviews briefly the history of the discovery of the earth's magnetism and its general characteristics. A map is included showing an inferred course of position of the earth's axis, based on variations in the direction of magnetization of rocks of different ages, which indicates that in Cambrian time, for instance, the north pole was in the Pacific Ocean at latitude about 20 degrees. The author considers that reversed magnetization of rocks indicates an actual reversal of the earth's magnetic field and reviews the electro-dynamic mechanisms which have been suggested to account for such a reversal.

"The Earth's Gravity" by Weikko A. Heiskanen (Director of the Institute of Geodesy Photogrammetry and Cartography at Ohio State University) first outlines the gross differences in gravity from equator to pole and includes a table of theoretical corrections for certain athletic contests which should be made on the basis of the variations of gravity with latitude. The relation of gravity to irregularities in the geoid and the possibility of calculating the shape of the geoid from world-wide, gravity measurements and the deflection of the vertical are outlined briefly. These relations are important for accurately relating maps of different parts of the world which cannot be directly connected by triangulation. The world-wide net of gravity values is being developed from Government and oil company gravity observations on land and now with some 4,000 measurements at sea and is being coordinated at Ohio State University. This program is to check the dimensions of the earth, to find the exact shape of the geoid, and to convert the several existing geodetic systems into an accurate reference system over the entire earth.

At the back of the magazine (pages 206–210) there is appended a bibliography of from 2 to 5 books or journal titles which are pertinent to each article.

L. L. NETTLETON
Gravity Meter Exploration Company
Houston, Texas

Structure and Origin of the Alps, Leopold Kober, Second Edition, Franz Deuticke, Vienna.

The author has remarkably summarized and synthesized the tremendous amount of available literature. European geologists have studied this area intensively for more than one hundred years and have postulated numerous theories of the origin and structure of this major geotectonic feature. To obtain a more complete understanding of the mechanism involved, it is necessary that the geophysical and geochemical aspects be considered, as well as the geologic evidence. The author has gone one step further, devoting a considerable portion of this book to the subjects of "alpine, telluric, and cosmic dynamics." He discusses in some detail his conception of "the gravitational evolution" of the earth and its effect on alpine evolution. According to this theory the density of the earth was originally 1.0 during cosmic times and eventually will be 7.5 at some time in the very distant future. Irrespective of the pros and cons of this theory, the author's approach to the solution of the problem of alpine dynamics and geocosmogony is another example of the need for integrating and applying physics, mathematics, and chemistry to solve major geologic problems.

In addition to a rather complete bibliography of published literature, a section is included in which doctors' theses involving many geologic phases of alpine studies are listed chronologically. A series of fifteen representative cross-sections showing typical alpine structure is a very useful addition to the many pertinent illustrations presented in this volume. These cross-sections can serve as a base for plotting available gravity and seismic information of the alpine region to obtain a better understanding of the fundamental relationships between the upper and lower portions of the earth's crust in this area. A brief mention is made of the gravity characteristics of the alpine area, and a map,

published in 1918, is included which shows Bouguer anomalies in the Swiss Alps. However, a great deal more geophysical data are available than are discussed in this book.

The reviewer would recommend this work to anyone wishing to get an understanding of the fundamental structural characteristics of the Alps and contiguous areas without resorting to the voluminous literature on the subject. For those wishing to pursue the study in more detail the excellent bibliography can be used to good advantage. However, no mention is made of a very recent volume, "The Geology of the Swiss Alps," by J. Cadisch, published in 1953.

RICHARD A. GEYER

Glossary of Selected Geological Terms, W. L. Stokes and D. J. Varnes, Colorado Scientific Society, Denver, Colo., 1955, XII+165 pp; $3.50 Cloth Bound, $2.75 Paper Bound.

This glossary, containing some 2700 entries, will be found very useful by geophysicists. It was prepared primarily to meet the needs of engineers and other specialists in fields related to geology. Although it does not include the jargon of the geophysical profession, nor specialized terms from the fields of mineralogy and paleontology, the broad field of general geology is very well covered. The style is semi-encyclopedic; many entries give much useful and interesting material in addition to definitions of terms. The page size of the volume (6×9 inches), and the type faces used make the glossary very convenient to use as a ready reference.

Both authors are connected with the U. S. Geological Survey and had the assistance of many of their colleagues in the compilation of the work. However, the glossary does not represent the official opinions or usages of the Survey. A preliminary draft of the glossary was submitted to several score geologists and engineers for criticism. For that reason, the geophysicist lacking geological training can be assured that the definitions given are generally acceptable to the geological profession.

The need for an up-to-date glossary of geologic terms is evidenced by the fact that a very comprehensive glossary is now being prepared under the auspices of the American Geological Institute. When published, this volume will not necessarily supplant more limited glossaries such as the one under review. A desk size dictionary is handy to have at hand even though an unabridged version is available.

W. T. BORN

Theories of the Earth's Magnetism, D. R. Inglis, *Reviews of Modern Physics*, Vol. 27, No. 2, April, 1955, pp. 212–248.

Previous reviews in GEOPHYSICS (XIX, No. 1, Jan. 1954, p. 68 and Vol. XX, No. 3, July, 1955, p. 699) have dealt with observations of the inverse magnetization of rocks and the question of whether this effect may be caused by magnetic properties of the rocks or by actual reversals of the main magnetic field of the earth. The present paper considers the physical basis of several different mechanisms proposed to account for the field. It is of interest in connection with the studies of rock magnetism because some of the mechanisms would allow reversal of the field.

The problem is to account for a field which is gradually changing, but remaining correlated with the axis of rotation and for the westward drift (the line of zero declination, which now is in America, was in Europe 400 years ago). The basic properties of the earth involved are a fluid metal core around a solid inner part and enclosed in a less conducting mantle. The "magnetohydrodynamics" of such a system, subject to gravitational and rotational forces and with possible heat sources and convection currents becomes very complex and has not been solved mathematically.

Some of the proposed mechanisms are quite complex and the paper, although apparently very carefully written, requires much study. The mathematical background is given for the various theories and, throughout the paper, quantitative estimates are carried out to determine whether or not the various mechanisms appear competent to produce effects of the required order of magnitude. Several of the processes are explained in terms of mechanical models, some of which are quite complex.

A section on "Convection and Relative Rotation with the Core" leads to a consideration of several induction theories. The Dynamo Theory is explained by a series of increasingly complex merry-go-

rounds, with several mutually dependent rotating elements and axes which correspond with circulatory motions and corresponding electric current circuits in the conducting core. Such a system acts like a self-excited electric generator which is regenerative, but the direction of the current (and the resulting magnetic field) depends on an accidental small initial magnetization. It is conceivable that such a system could become degenerative and then build up again, possibly in the opposite direction. Thus the field would be parallel with the axis of rotation but might reverse itself. The mechanism also explains the westward drift. Consideration of energy sources, the energy of the magnetic field and its rate of dissipation indicate that there should be an excess of energy to account for losses and inefficiency factors. Certain aspects of the possible motions within the fluid core are comparable with motions in the atmosphere and the effects of a possible jet-stream, similar to that in the upper atmosphere, are considered. Another type of regenerative system depends on a "twisted kink" of magnetic lines.

In addition to the Dynamo Theory and its many complications there are several other possible mechanisms. Effects of pressure on the lattice structure of metals can give rise to a thermoelectric effect. Also, there are pressure effects which could contribute to regeneration of the field. These rather complex possibilities provide other possible mechanisms which are quite different from that of the Dynamo Theory.

In the "concluding remarks" it is pointed out that a clear choice between several competing mechanisms is not yet possible. Rather than a paucity, there is a wealth of theoretically possible origins of the field. It will require much time and study before a generally acceptable answer is found for the source of the magnetic field of the Earth even though it has been known and studied for hundreds of years.

L. L. NETTLETON

The Electrical Effects of Tidal Streams in Cook Strait, New Zealand, B. H. Ollson, *Deep-Sea Research*, Vol. 2, No. 3, April, 1955, pp. 204–212.

When sea water flows, in response to tidal or other forces, across geomagnetic flux lines an electromotive force is set up of the same type that would be observed if any other conductors, such as a wire, were to move across the same flux lines at the same rate. This electromotive force has been measured by electrodes in the water. If the flow occurs close to shore, it can be detected by measuring the earth currents set up by the voltage induced in the water. Tidal flow in the English Channel has been recorded by pairs of buried electrodes along the adjacent shore.

This paper described an electrode installation set up near Wellington, New Zealand, to study the feasibility of recording tidal flow in Cook Strait with shore-based electrodes. Two pairs of electrodes were used, the north-south electrodes were one kilometer apart and the east-west electrodes 1½ kilometers apart. The two lines were located as near as possible to the edge of the strait. An automatic recorder giving a full-scale reading of 400 millivolts plotted the instantaneous value of voltage once each minute on a clock-driven chart.

The best curve through the plotted points was clearly sinusoidal although there was a large scatter of points which was attributed to street cars in nearby Wellington. The periodicity of the variation in electrical potential was found to correlate well with the tidal cycle in the strait as determined by conventional methods. The peak-to-trough amplitude of the electrical variations was found to be about 50 millivolts per kilometer of electrode separation. For some reason not well understood, the base line turned out to be much closer to the troughs of the potential curves than to the peaks, indicating a predominance of positive potentials over the tidal cycle.

Applying the theory of Longuet-Higgins relating flow through a channel to the earth currents induced by the flow, the Wellington observations indicated a tidal velocity of two knots. Observations with current meters in the strait indicated a speed of 1½ knots, thus establishing a fair degree of accuracy for the shore-electrode method of recording tidal flow.

MILTON B. DOBRIN

The Problem of Rheology, A. V. Brancher, *Petroleum*, Vol. XVIII No. 10, October, 1955, p. 373–380.

Rheology, "applicable to any process in which flow occurs under a stress stimulus," has of long been a concern of geologists concerned with the deformation of rocks. Recently it has come to the fore as a problem involved in many materials, including oils, plastics, cements, and metals. The more economic aspect of these materials has brought the subject under the eyes of physicists, chemists, and mathematicians. Any student of geology who has tried to master the confusing experimental data and the terminology of the geologic treatises on rock deformation would appreciate the entrance of the other sciences.

Dr. Brancher's article is subtitled "A Current Appraisal." The development of the science to its current status is treated briefly in the introduction. The subsequent section headings are viscosity-temperature function, visco-plastic flow, visco-plastic sheets, slider bearing lubrication, metallic creep, the transient function, dynamical analogy, conclusion.

The first section, excluding the introduction, in the main summarizes equations applicable to a Newtonian liquid. It then admits of their inapplicability to non-Newtonian materials, recognizing the well-known fact that "flow properties of highly viscous materials cannot be measured by conventional means." Therefore, extrusion methods are employed, and these are reviewed in the second section.

The third section discusses a parallel between the "calendering" process, used in the manufacturing process of linoleum, and metal rolling. Again the section concludes, after a summary of existing formula and data, with the fact that further work is necessary before non-Newtonian solutions are valid.

The section on metallic creep is disappointingly short to those interested in geologic phenomena. The section on dynamical analogy utilizes an ideal spring and a dashpot. The analogy is limited in its application, of course, but it is easily usable within its confinement. Passing mention is made to the use of electric analog methods to further these investigations.

The article closes with a tabulation of nomenclature and a list of up-to-date references. Of course, this brief appraisal only skirts the problem of the deformation of materials. In doing so, however, it permits one to appreciate the possibilities from systematically attacking a problem of vital importance to those concerned with earth deformation.

Nelson C. Steenland
Gravity Meter Exploration Company
Houston, Texas

On Forms of Seismic Waves Generated by Explosion, I, Ziro Suzuki and Hiromu Sima, *The Science Reports of the Tohoku University, Geophysics*, Vol. 5, 1954, pp. 85–94.

During February, 1953, "The Group for Experimental Research of Seismic Exploration" of Tohoku University undertook an experimental program whose purpose was to determine empirically the laws governing the propagation of elastic waves generated by an explosion. This is the first report of their results.

The seismograms analyzed were taken with 20 cps geophones coupled directly to 50 cps galvanometers. The spread length was 11.25 to 20.25 meters. This choice of geophone and galvanometer natural frequencies, although probably necessary to avoid amplifiers, would seem to limit the recorded frequency band. A cap fired 75 centimeters below the surface was the source.

Suzuki and Sima found that the ground motion consisted of a number of wave groups traveling with different velocities, that the periods of the waves in a group remained constant, that the amplitude of an arrival normalized to a standard amplitude varied linearly with distance, and that later events became more important with increasing source-detector separation. None of these conclusions is new or startling. Similar results have been obtained previously by a number of investigators both in the field and with seismic models. Nor is the analysis of the data complete. While the authors do present a travel time-distance plot for all cycles on their records, they do not calculate a group

velocity curve for the four distinct sets of arrivals. The associated concept of dispersion would clarify some of the results reported. The authors further handicap the serious reader by giving no description even the first few hundred feet of earth section.

The reviewer feels that the Tohoku University groups have started an interesting investigation but that the presentation is naive and incomplete. A little theory may help even the most determined empiricist.

FRANKLYN K. LEVIN

Glancing Angle Reflection of Elastic Waves From a Free Boundary, E. C. Roesler, *Phil. Mag.*, Vol. 4, No. 376, pp. 517–526, May, 1955.

If one applies classical elastic theory to the case of an irrotational wave incident upon a free boundary at the glancing angle, the solution indicates that both the shear wave and compressional wave have zero amplitudes. Thus, one would expect neither motion nor stress anywhere. If a compressional wave passes through a solid with its direction of propagation parallel to a thin cut in the solid, a travelling shear wave is generated at the cut.

This shear wave trails the compressional wave at an angle β which is equal to $\sin^{-1} C_2/C_1$ where C_2 is the shear velocity and C_1 is the compressional velocity. The generation of the shear wave is actually a diffraction phenomenon but it can be explained theoretically as a reflection process. Thus, non-vanishing motion can be demonstrated at least for special cases of glancing angle reflection.

The author works out a rather elementary treatment for the reflection of shear waves and compressional waves when an incident wave strikes a boundary at an angle approaching 90°. By passing to the limit, he shows how the trailing shear pulse is required to satisfy the boundary conditions at the free surface. The amplitude relations are expressed in terms of very small differential quantities which can be determined by photo-elastic methods. A companion paper described some experiments which confirm these predictions.

MILTON B. DOBRIN

Reflection of Elastic Waves From a Free Boundary, D. G. Christie, *Phil. Mag.*, Vol. 46, No. 376, May, 1955, pp. 527–541.

The experiments described in this paper were carried on with the objective of studying the reflection of the elastic waves from the surface of an elastic half-space, i.e. a plane boundary of a semi-infinite medium. The author demonstrates that this phenomenon can be simulated by the propagation of a plane pulse travelling through a semi-infinite plate and reflected from its free edge. This conclusion was also reached by Press and Oliver when they developed their two-dimensional model to simulate three-dimensional wave propagation.

The plates used in this experiment were stress-birefringent, so that photoelastic techniques could be used to study the pulse propagation. The pulses were observed under polarized light as interference fringes. The amplitude of the waves was determined by counting the number of fringes.

Theory was worked out for the reflection of a plane dilatation pulse from the edge of a plate as a function of the angle of incidence. The amplitude of the pulse appears, both for the compressional and the shear reflection, to vary with angle of incidence in the same manner as for a wave reflected from a free plane surface.

The most interesting feature of this paper is a series of photographs demonstrating the reflection of *P* and *S* pulses from a free edge at various angles of incidence up to the glancing angle. A sheet of "Perspex" was employed for these experiments. The source of signal was a detonating fuze along one edge of the sheet. The detonation was started at one end of the fuze and the pulse travelling along the edge generated a linear wave front instead of the circular front that would have resulted from a point source. The waves striking the boundary were observable under polarized light and the propagation of the incident pulse, the reflected *P* pulse, and the reflected *S* pulse could all be seen individually. A camera was focused on the reflecting edge and a series of sparks was employed at predetermined time intervals tens of microseconds apart so that a sreies of pictures could be obtained which showed the progress of the travelling waves before and after reflection. An ingenious technique

was used to obtain a series of pictures at different times all on different parts of the same plate. This avoided the difficulties that would have been involved if motion pictures had been required.

Wave amplitudes were measured from the photographs by counting fringes and the theoretical curves for the relative amplitude of reflected shear and reflected compressional waves were plotted as a function of angle of incidence. Very good agreement was obtained with theory, and the values observed at glancing incidence confirmed the theory worked out by Roesler for the paper discussed in the previous review.

MILTON B. DOBRIN

Note on the Propagation of Normal Modes in Inhomogeneous Media, Ivan Tolstoy, *Journal of the Acoustical Society of America*, Vol. 27, 1955, pp. 274–277.

In this paper Dr. Tolstoy derives the characteristic equation governing the dispersion of undamped normal modes for an inhomogeneous medium. The inhomogeneous section he considers is of thickness H and lies between spaces extending to $+\infty$ and $-\infty$. Both a multilayered medium and one with continuously varying properties are treated; in either case there is a zone or bed within the inhomogeneous section with sound velocity less than that of the two half-spaces. By expressing the reflection coefficients as rotations, Tolstoy obtains a formally simple period equation.

The normal mode solutions for inhomogeneous media might seem to have little immediate application in exploration geophysics but those who have had to deal with dispersive ground roll know this is not true. The cases treated by Tolstoy as representations of reasonable earth sections are of particular interest and the derived equations should have wide application. However, the geophysicist who starts to read this paper should expect difficulties. In the process of preparing the manuscript for publication, Tolstoy reduced a fifty page exposition to a terse four pages. The result is an interesting contribution to the growing literature in the field but it is not easy to follow.

FRANKLYN K. LEVIN

PUBLICATIONS RECEIVED

American Journal of Science, v. 253, nos. 8, 9 & 10 (Aug., Sept. & Oct. 1955)
Annales de Geophysique, v. 8, no. 2, v. 11, no. 2 (1955)
Bulletin of The Earthquake Research Institute, v. 33, part 1 (March 1955)
Bulletin d'Information de l'U.G.G.I., v. 4, nos. 9 & 10 (March & June 1955)
Bulletin of the Seismological Society of America, v. 45, no. 3 (July 1955)
Butsuri-Tanko (Geophysical Exploration), v. 8, no. 2 (1955)
Deutsche Hydrographische Zeitschrift, v. 7, no. 5/6 (1954)
Department of Mines South Australia, Geological Survey, no. 3 (1955)
Economic Geology, v. 50, nos. 6 & 7 (Sept., Oct. & Nov. 1955)
Erdol und Kohle, v. 8, nos. 7, 8 & 9 (July, Aug. & Sept. 1955)
Geofizikai Kozlemenyek, v. 4, no. 1 (1955)
Geological Abstracts, v. 3, no. 2 (Sept. 1955)
Geologisches Jahrbuch, no. 69 (1955)
The Geology of Greece, nos. 2, 3, 4 & 5 (1951)
Geophysical Abstracts, v. 161 (April & June 1955)
Geophysical Prospecting, v. 2, nos. 2 & 4 Reprints (1954), v. 3, nos. 2, 3 & Supplement (1955)
Gerlands Beitrage Zur Geophysik, v. 64, no. 4 (1955)
Journal Academy Science USSR, Series Geophysical, nos. 1, 2, 3 & 4 (1955)
Journal of Geophysical Research, v. 60, no. 3 (Sept. 1955)
Journal of Petroleum Technology, v. 7, no. 8 (Aug. 1955)
Journal of the University of Moscow, nos. 2 & 3 (1955)
Meteoros, v. 5, nos. 1 & 2 (Jan. & June 1955)
The Mineral Wealth of Greece, v. 1 (1951), v. 2 (1952)
Mining Engineering, v. 7, no. 8 (Aug. 1955)
Petroleum Economy, nos. 2–9 (1955)
Proceedings of the Cambridge Philosophical Society, v. 51, no. 3 (July 1955)
Quarterly Journal of the Geological Society of London, v. 111, part 441 (Sept. 13, 1955)
Rapport Microseismique De L'Institut National Seismologique De Hongrie, Series A (1951, 1952 & 1953)
Revista di Geofisica Applicata, v. 15, no. 2 (1954)
Rocznik, v. 23, no. 3A (1953)
Science, v. 122, nos. 3162–3174
The Science Reports of the Tohoku University, v. 7, no. 1 (Aug. 1955)
Scientific Monthly, v. 81, nos. 3 & 4 (Sept. & Oct. 1955)
Tellus, v. 7, no. 2 (May 1955)
Transactions American Geophysical Union, v. 36, no. 4 (Aug. 1955)
Tulsa Geological Society Digest, v. 23 (1955)
Ungarischer Erdberbenkatalog, Series B (1951 & 1952)

NEW BOOKS RECEIVED

Horner, J. G., 1955, Dictionary of Mechanical Engineering Terms: New York, Philosophical Library, Inc.

Jay, K. E. B., 1955, Atomic Energy Research in Hawell: New York, Philosophical Library, Inc.

DISCUSSIONS AND COMMUNICATIONS

LETTER TO THE EDITOR

November 10, 1955

DEAR SIR,

Considering that all the fundamental work in physics is done in the metric system, and that it is important that results obtained in the U. S. be readily comparable with those obtained elsewhere, I think it would be desirable that the authors of papers to be published in GEOPHYSICS be asked to give their measurements also (or only, if they prefer) in the metric system. For instance: "The velocity is 3,500 ft/sec (1.067 km/sec)."

It is realized that this may involve a little more labor, but as there appears to be general agreement on the advantages of the metric system, it is probably better to make the effort to switch over now; certainly as time passes it will become more and more difficult to do so.

Sincerely yours,
J. CL. DE BREMAECKER

EDITOR'S NOTE: Dr. J. Cl. De Bremaecker is a geophysicst with the Institut pour la Recherche Scientifique en Afrique Centrale, Belgian Congo, and is on leave from his work for a year which he will devote to study at Lamont Geological Observatory on a Boese postdoctoral fellowship.

ERRATA

In paper "Magnetic Delay Line Filtering" by Hal J. Jones, John A. Morrison, G. P. Sarrafian, L. J. Spieker, GEOPHYSICS v. 20, pages 754 and 761, Fig. 6c and Fig. 13 were inadvertently interchanged.

In paper "Simultaneous Gamma Ray and Resistance Logging as Applied to Uranium Exploration" by R. A. Broding and Ben F. Rummerfield, GEOPHYSICS, v. 20, p. 841–859, on page 847 under RADIOMETRIC ASSAYING line 9 in place of 50% read 20%.

MEMORIAL

LE VALLEY IRVING BROCKWAY

L. I. Brockway, known to his friends as "Brock," died of a heart attack at his home on the morning of June 16th at Bakersfield, California. He had had a long and varied career in geophysics, and had just completed his twentieth year with the Gulf Companies.

He was born at Owosso, Michigan on February 17, 1911. There he attended high school and met Alice, whom he married in 1935. Brock's main interests centered around his family of four school age daughters, Katherine, Barbara, Elizabeth, and Nancy.

He attended Michigan State College from 1930 to 1934, where he graduated with a degree in electrical engineering. Starting in 1935 in the geophysical department of the Gulf Oil Corporation, he worked as observer and at other field seismograph party jobs until 1942. From 1942 to 1944 he worked on the development and field testing of special seismograph instruments, and in 1944 transferred to the Gulf laboratories near Pittsburgh, where he worked on geophysical instrument development. From 1945 to 1947 he served as field geophysical in-

strument supervisor, and was observer and adviser in electronics at the atom bomb tests in the Pacific in 1946.

In 1947 he transferred to Calgary to take charge of Gulf's entire Western Canada geophysical operations until 1953. While there he served as technical adviser to the Canadian Broadcasting System on a radio program entitled "Oil in Canada." After a short assignment at the Gulf Pittsburgh laboratory, he came to California in 1953 in the capacity of Chief Geophysicist for the Western Gulf Oil Company.

Brock was always on the go, and his enthusiasm for his work and for the future of the California oil industry, was contagious. His wealth of new ideas was an inspiration to his associates. He was a good bowler and Saturday golfer, where his companionship was sought for his easy wit and good humor. Professional and amateur sports events occupied his continued interest.

He was a member of the Society of Exploration Geophysicists and served as Vice President of the Calgary Section in 1951 and President in 1952. He was currently Secretary-Treasurer of the Pacific Section. Other memberships were in the American Association of Petroleum Geologists, the American Geophysical Union, and the Canadian Engineering Society.

P. F. CLEMENT

September 26, 1955

CONTRIBUTORS

FRANCIS COLLINS

FRANCIS COLLINS was born in Houston in 1917. He entered Rice Institute in 1935 with the intention of preparing for a journalistic career. In 1939 he was graduated with a B.A. degree and an interest in science and engineering. In 1942 he received his B.S. in electrical engineering and joined the general engineering staff at the Sylvania Electric Products, Inc. radio tube plant in Emporium, Pennsylvania. In 1943 he was transferred to the Sylvania circuit research laboratory in Flushing, New York, and a year later to the patent law department in Bayside, New York. During this period he attended the evening graduate school at Stevens Institute of Technology, and subsequently received his M.S. degree in electrical engineering in 1950.

Since 1946 he has been with The Atlantic Refining Company in the research and development department in Dallas. Until 1952 he worked on mathematical methods for carrying out reservoir engineering calculations. Since that time he has worked on mathematical problems arising in connection with new or improved methods of prospecting or well-logging. His chief interests at present are the theory of wave propagation and the application of digital computers. He is also a lecturer in the evening graduate school at Southern Methodist University, where he occasionally gives a course in the analysis of nonlinear systems.

He is a member of the Society of Exploration Geophysicists and of several other professional and honorary societies.

KENNETH L. COOK

KENNETH L. COOK received a B.S. degree in Physics in 1939 from the Massachusetts Institute of Technology. During the next four years he continued his studies in geology and physics at the University of Chicago, at the same time engaging in part-time teaching duties as a University Fellow and, during the last two years of attendance, as Instructor. Also he taught a course in Geophysical Exploration for Oil at the University of Chicago in 1941. In 1943 he received a Joint Ph.D. degree in Geology and Physics from the University of Chicago. Since 1943 he has been actively engaged in geophysical field work as geophysicist in the Division of Geophysical Exploration of the U. S. Bureau of Mines (1943 to 1946) and in the Geophysics Branch of the U. S. Geological Survey (1946 to present; currently on a part-time basis). This field work has comprised chiefly strategic-mineral investigations in mining districts of the West, in which he has employed magnetic, gravitational, electrical, and refraction seismic surveys as guides in the exploration. He has also made regional gravity surveys in parts of Maryland, Oklahoma, Kansas, and Utah; resistivity surveys in the Tri-State zinc and lead mining district; and magnetic surveys in Kansas. Since 1952 he has been Professor and Head of the Geophysics Department at the University of Utah.

He is a member of the American Geophysical Union, American Association of Petroleum Geologists, American Institute of Mining and Metallurgical Engineers, Geological Society of America, Seismological Society of America, Sigma Xi, and Society of Exploration Geophysicists. In the SEG he has been a member of the Reviews Committee (1949–53), the Sub-Committee of the Mining Geophysics Case Histories Volume (1953–55), the Geophysical Activities Committee (1954–55). He indexed the technical papers for the recently published SEG Cumulative Index.

V. U. GAITHER received his college training at East Central State Teachers College, Ada, Oklahoma, and the University of Oklahoma. He received a B.A. degree in Education in 1927 and a B.S. degree in Mathematics and Science in 1932. Intermittently while attending school and after graduation, he served as teacher, principal and superintendent in the Public Schools of Oklahoma. He was employed by Continental Oil Company in the summer of 1944 and has remained with that company since that time. His experience with Continental has been in the various phases of seismic operations and at present he is a Geophysicist in the Operations Division, Geophysical Section at Ponca City.

Mr. Gaither has been a member of the Society of Exploration Geophysicists since 1946.

V. U. GAITHER

ALVIN R. GREGORY

ALVIN R. GREGORY received his B.S. degree in Chemical Engineering from the University of Texas in 1938. After some graduate training and a brief employment by Cities Service Oil Company, he served in the U. S. Navy for four years as a Radar Officer. In 1945 he was employed by Phillips Petroleum Company and spent six years in their production and geophysics research departments. Since 1951 he has been associated with Gulf Research & Development Company where he is employed as a chemist. He is a member of the American Institute of Mining and Metallurgical Engineers.

CHWAN-CHANG LEE

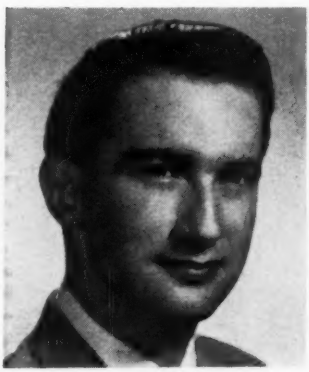
CHWAN-CHANG LEE attended the University of Utopia in Shanghai, receiving his B.S. degree in electrical engineering in 1949 and immediately departing for the United States for graduate study at the University of Texas. Here he received his M.S. degree in electrical engineering in 1951 and the Ph.D. degree in 1953.

Joining The Atlantic Refining Company's research and development department in Dallas, he has since been engaged primarily in theoretical analyses related to prospecting and well-logging methods. He is also a graduate lecturer in the electrical engineering department of Southern Methodist University.

Dr. Lee is a member of the Society of Exploration Geophysicists, Eta Kappa Nu, and Sigma Xi.

TERRY W. SPENCER received the B.A. degree with highest honors in physics at the University of California at Los Angeles in 1951. The following year he began graduate studies in physics at Massachusetts Institute of Technology where he served as a teaching assistant. Later in 1952 at California Institute of Technology he was awarded the Lane Wells Fellowship in Geophysics which he has held continuously for the last three years. During that time he has been engaged in basic research on problems in acoustic pulse propagation.

Mr. Spencer is a member of Phi Beta Kappa and an associate member of the Society of Sigma Xi.



TERRY W. SPENCER

Biographies and photographs of the following authors may be found in recent issues of GEOPHYSICS: Sigmund Hammer, v. 20, p. 710 (July, 1955); M. R. J. Wyllie, v. 20, p. 969 (October, 1955).

SOCIETY ROUND TABLE

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Sigmund Hammer ('58) — Roy L. Lay ('60)

Standing Committee on Publications

Chairman: John P. Woods, The Atlantic Refining Co., Dallas, Texas

L. L. Nettleton — Cecil H. Green
H. B. Peacock — Sigmund Hammer

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F. K. Levin — Daniel Linehan, S.J. — Frank Press
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Kumiji Iida — R. G. Piety

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Standing Committee on Safety

Chairman: W. H. Newton, General Geophysical Co., Houston, Texas

G. M. Kintz — Robert N. Brantley — Wendall H. Hawkes
Eugene L. Wells — Paul M. Hanahen — Bart W. Sorge
R. C. Henderson — Elmer Johnson

Special Committee on Geophysical Case Histories Volume II

Chairman: D. P. Carlton, Humble Oil and Refining Company, Houston, Texas
Editor: Paul L. Lyons, Sinclair Oil and Gas Co., Tulsa, Oklahoma

R. A. Peterson — Frank Goldstone — P. M. Konkel
Norman J. Christie — John H. Wilson — Stefan Von Croy
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T. I. Harkins — Sigmund Hammer — J. Brian Eby
Marvin Romberg — W. H. Fenwick — E. S. Sherar
W. W. Newton — C. H. Dresbach — L. L. Nettleton
O. C. Clifford — R. M. Bradley — Eugene W. Frowe
Dean Walling — W. L. Matjasic — H. C. McCarver
R. F. Beers — A. B. Bryan — Roy L. Lay

Subcommittee on Mining Case Histories

Chairman: HAROLD O. SEIGEL, Consultant, Toronto, Canada

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ROBERT G. VAN NOSTRAND
J. EWART BLANCHARD
SHERWIN F. KELLY

SPECIAL COMMITTEE ON CONSTITUTION AND BYLAWS

Chairman: W. M. RUST, JR., Humble Oil & Refining Co., Houston, Texas

HENRY C. CORTES
CECIL H. GREEN
ANDREW GILMOUR
SIGMUND HAMMER
J. J. JAKOSKY
L. L. NETTLETON

SPECIAL COMMITTEE ON STANDARDIZATION OF MAGNETIC RECORDING OF SEISMIC SIGNALS

Chairman: R. R. THOMPSON, Humble Oil & Refining Co., Houston, Texas

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J. E. HAWKINS
K. M. LAWRENCE
B. D. LEE
R. A. PETERSON
F. A. VAN MELIE
G. B. LOPER

Subcommittee on Definitions and Measurements

Chairman: (To be appointed)

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FRANK COKER
LOUIS W. ERATH
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ROBERT C. MOODY

Subcommittee on Information on Magnetic Recorder Characteristics

Chairman: (To be appointed)

SPECIAL COMMITTEE ON RESEARCH

Chairman: DAYTON H. CLEWELL, Magnolia Petroleum Co., Dallas, Texas

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J. B. MACELWANE, S. J.
B. D. LEE
H. F. DUNLAP
J. M. CRAWFORD
DANIEL SILVERMAN
J. E. WHITE

SPECIAL COMMITTEE ON INDEX OF WELLS SHOT FOR VELOCITY

Chairman: V. U. GAITHER, Continental Oil Company, Ponca City, Oklahoma

ADVISORY COMMITTEE ON RADIOACTIVE MINERAL EXPLORATION

(Joint committee of AAPG, SEPM, and SEG)

1955	1956	1957
CECIL H. GREEN*	GERHARD HERZOG*	ROLAND F. BEERS*
MORTON T. HIGGS	ROBERT R. RIEKE	JEAN C. FINLEY
J. HARLAN JOHNSON	WILFRED B. TAPPER	HAROLD N. FISK
	GERALD H. WESTBY*	RONALD E. MCADAMS
		H. E. STOMMEL*

* SEG Members.

DIRECTORS OF THE AMERICAN GEOLOGICAL INSTITUTE

ROY L. LAY ('56) PAUL L. LYONS ('57)

REPRESENTATIVE TO DIVISION OF EARTH SCIENCES
NATIONAL RESEARCH COUNCIL

C. B. BAZZONI

REPRESENTATIVE ON COUNCIL OF
AMERICAN ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE

ROLAND F. BEERS, Beers and Heroy, Troy, N. Y.

LOCAL SECTIONS

GEOPHYSICAL SOCIETY OF TULSA

(CHARTERED FEBRUARY 2, 1948)

President: JOHN M. CRAWFORD, Continental Oil Co., Ponca City, Okla.
1st Vice-President: STANLEY WILCOX, Seismograph Service Corp., Box 1590, Tulsa 1, Okla.
2nd Vice-President: WILLIAM M. ERDAHL, Skelly Oil Co., Box 1650, Tulsa, Okla.
Secretary: JOHN RUPNIK, Consultant, Jenkins Bldg., Tulsa, Okla.
Treasurer: R. B. RICE, Phillips Petroleum Co., Bartlesville, Okla.
Editor: E. V. MCCOLLUM, E. V. McCollum & Co., 515 Thompson Bldg., Tulsa, Okla.
District Representatives:
NORMAN RICKER ('56), The Carter Oil Co., Box 801, Tulsa, Okla.
W. T. BORN, Geophysical Research Corp. ('56), 2607 N. Boston, Tulsa, Okla.
L. Y. FAUST ('57), Amerada Petroleum Corp., Box 2240, Tulsa, Okla.
Meetings: Monthly, 2nd Thursday, 7:00 P.M., meeting only, University of Tulsa, Room 224, Petroleum Science Hall.

SOCIETY OF EXPLORATION GEOPHYSICISTS HOUSTON SECTION

(CHARTERED FEBRUARY 14, 1948)

President: W. HARLAN TAYLOR, Taylor Exploration Co., 2118 Welch Avenue, Houston, Texas
1st Vice-President: J. F. FREEL, Research Exploration, Inc., Box 13275, Houston 8, Texas
2nd Vice-President: JOHN BYERS, States Exploration Co., 709 M&M Bldg., Houston, Texas
Secretary: S. BROOKS STEWART, Sohio Petroleum Co., 1964 W. Gray, Houston 12, Texas
Treasurer: M. L. BENKE, American Republics Corp., 2111 Wroxton Rd., Houston 5, Texas
District Representatives:
O. T. LAWHORN ('57), Pan American Production Co., 1223 Esperson Bldg., Houston, Texas
W. T. LEA ('57), Cities Service Oil Co., 1440 Esperson Bldg., Houston 2, Texas
Meetings: Monthly, 1st Monday, Noon luncheon ($1.50), Rice Hotel.

PACIFIC COAST SECTION

(CHARTERED APRIL 12, 1948)

President: JOHN W. MATHEWS, Richfield Oil Co., Box 147, Bakersfield, Calif.
Vice-President Northern District: RICHARD W. SHOEMAKER, Ohio Oil Co., Box 193, Bakersfield, Calif.
Vice-President Southern District: ELLSWORTH M. CURRY, Shell Oil Co., 1008 W. 6th St., Los Angeles 17, Calif.
Secretary-Treasurer: I. V. SCHERB, The Texas Co., Box 3127, "H" St. Annex, Bakersfield, California
District Representatives:
FLINT H. AGEE, United Geophysical Corp., 2227 S. 4th Ave., Arcadia, Calif.
WM. D. CORTRIGHT, Tide Water Associated Oil Co., 2202 Terrace Way, Bakersfield, Calif.

MILTON C. BORN, Amerada Petroleum Corp., 552 Subway Terminal Bldg., Los Angeles, Calif.
Meetings: Monthly, 2nd Thursday, Noon luncheon ($2.00), Biltmore Hotel, Los Angeles.

DALLAS GEOPHYSICAL SOCIETY

(CHARTERED AUGUST 7, 1948)

President: JOHN A. LESTER, Magnolia Petroleum Co.
1st Vice-President: H. F. DUNLAP, The Atlantic Refining Co.
2nd Vice President: GLENN M. CONKLIN, Sun Oil Co.
Secretary-Treasurer: M. S. HATHAWAY, The Atlantic Refining Co.
District Representatives:
O. C. CLIFFORD, JR., The Atlantic Refining Co., Box 2819, Dallas 1, Texas
CECIL H. GREEN, Geophysical Service Inc., 5900 Lemmon Ave., Dallas 9, Texas
J. P. WOODS, The Atlantic Refining Co., Box 2819, Dallas 1, Texas
Meetings: Monthly, generally but not invariably 2nd Monday (contact any member). 8:00 P.M. Fondren Science Bldg., S.M.U.

FORT WORTH GEOPHYSICAL SOCIETY

(CHARTERED AUGUST 7, 1948)

President: H. E. ITTEN, Empire Geophysical Inc., 1008 Neil P. Anderson Bldg., Fort Worth 2, Texas
Vice-President: RICHARD BREWER, Continental Geophysical Co., 602 Continental Life Bldg., Fort Worth 2, Texas
Secretary-Treasurer: CARL WERT, Gulf Oil Corp., Drawer 1290, Fort Worth 1, Texas
District Representatives:
FRANK MORTLOCK, Gulf Oil Corp., Drawer 1290, Ft. Worth 1, Texas
L. O. SEAMAN, Sinclair Oil and Gas Co., 901 Fair Bldg., Ft. Worth, Texas
Meetings: Monthly, 4th Monday, Noon Luncheons ($1.50), Texas Hotel.

ARK-LA-TEX GEOPHYSICAL SOCIETY

(CHARTERED MARCH 12, 1949)

President: B. B. BURROUGHS, Sunray Oil Corp., Ricou-Brewster Bldg., Shreveport, La.
Vice-President: JOHN APPENDINO, Union Producing Co., Box 1407, Shreveport, La.
Secretary-Treasurer: HERBERT J. FERBER, Gulf Oil Corp., Box 1731, Shreveport, La.
District Representatives:
J. RYAN WALKER, Arkansas Fuel Oil Corp., Box 1117, Shreveport, La.
B. B. BURROUGHS, Sunray Oil Corp., Ricou-Brewster Bldg., Shreveport, La.
Meetings: Monthly, normally last Monday, Noon Luncheon ($1.50), Captain Shreve Hotel, Shreveport.

PERMIAN BASIN GEOPHYSICAL SOCIETY

(CHARTERED JANUARY 30, 1950)

President: DECKER DAWSON, Dawson Geophysical Co.
1st Vice-President: MAXEY PINSON, Union Oil Co. of California
2nd Vice-President: W. A. SEAL, JR., Continental Geophysical Co.
Secretary: MALCOLM KNOCK, Stanolind Oil and Gas Co.
Treasurer: R. J. KNOTT, The Atlantic Refining Co.
Meetings: Monthly, 2nd Tuesday, 7:30 P.M., free coffee and doughnuts, Cowden Jr. High School cafeteria.

DENVER GEOPHYSICAL SOCIETY

(CHARTERED MAY 19, 1950)

President: E. B. WASSON, Cosden Petroleum Co., 1510 Denver Club Bldg., Denver, Colorado
Vice-President: C. E. RIDDEL, British American Oil Prod. Co., Box 180, Denver, Colorado

Secretary-Treasurer: J. E. THOMPSON, Sun Oil Co., Box 1798, Denver, Colorado
District Representative: C. C. O'BOYLE, Brainerd & Van Tuyl, 232 Empire Bldg., Denver, Colorado
Meetings: Monthly, 1st Monday, 5:30 P.M., meeting only, Petroleum Club.

CANADIAN SOCIETY OF EXPLORATION GEOPHYSICSTS

(CHARTERED JANUARY 24, 1952)

President: R. D. HOLLAND, Texaco Exploration Co., 237 7th Ave., W., Calgary, Alberta
Vice-President: E. G. HAINES, Seaboard Oil Co., 630 8th Ave., W., Calgary, Alberta
Secretary-Treasurer: H. J. MCGREW, Canadian Gulf Oil Co., Box 130, Calgary, Alberta
District Representative: F. G. COOTE, Accurate Exploration Ltd., 2201 10th Ave., W., Calgary, Alberta
Meetings: (Data not received)

GEOPHYSICAL SOCIETY OF OKLAHOMA CITY

(CHARTERED SEPTEMBER 30, 1952)

President: J. E. STONES, The Superior Oil Co., 2211 Liberty Bank Bldg., Oklahoma City, Okla.
1st Vice-President: R. D. ROBERTS, Sohio Petroleum Co., Box 3656, Oklahoma City, Okla.
2nd Vice-President: D. J. VAN NOSTRAND, Gulf Oil Corp., Box 9667, Oklahoma City, Okla.
Secretary: JOHN BEMROSE, Sohio Petroleum Co., Box 3656, Oklahoma City, Okla.
Treasurer: R. H. PEACOCK, Superior Oil Co., 2211 Liberty Bank Bldg., Oklahoma City, Okla.
District Representative: R. D. ROBERTS, Sohio Petroleum Co., Box 3656, Oklahoma City, Okla.
Meetings: Monthly, 2nd or 3rd Monday, time and place to be announced.

CASPER GEOPHYSICAL SOCIETY

(CHARTERED MAY 23, 1953)

President: G. NEWMAN SHELL, Cities Service Oil Co., 1719 S. Oak, Casper, Wyo.
Vice-President: GEORGE N. MEADE, Stanolind Oil & Gas Co., Box 40, Casper, Wyo.
Secretary-Treasurer: WESLEY N. FARMER, Richfield Oil Corp., Box 698, Casper, Wyo.
District Representative: HOMER ROBERTS, Petty Geophysical Engineering Co., Box 651, Casper, Wyoming
Meetings: Monthly, 1st Monday, 7:00 P.M., Dinner ($2.75), Townsend Hotel

GEOPHYSICAL SOCIETY OF SOUTH TEXAS

(CHARTERED NOVEMBER 9, 1953)

President: WELDON L. CRAWFORD, Petty Geophysical Engineering Co., Transit Tower, San Antonio Texas
Vice-President: LEE MOORE, Petty Geophysical Engineering Co., Transit Tower, San Antonio, Texas
Secretary-Treasurer: LAWTON B. STEPHENSON, Petty Geophysical Engineering Co., Transit Tower, San Antonio, Texas
District Representative: BART PRATT, Petty Geophysical Engineering Co., Box 2061, San Antonio, Texas
Meetings: Semi-monthly, 2nd and 4th Wednesdays, Noon luncheon (Cafeteria style), Sommers Cafeteria, Main Plaza, San Antonio.

SOUTHEASTERN GEOPHYSICAL SOCIETY

(CHARTERED APRIL 1, 1954)

President: G. A. BURTON, Shell Oil Co., Box 193, New Orleans, La.
Vice-President: J. A. HARRIS, The California Co., 800 The California Co., Bldg., New Orleans 12, La.
Secretary-Treasurer: J. B. MEITZEN, Humble Oil & Refg. Co., Box 626, New Orleans 7, La.

District Representatives:
CLARK E. ALLEN, Geophysical Service Inc., 522 Arlington Dr., New Orleans 20, La.
K. R. WELLS, General Geophysical Co., 5025 St. Bernard Ave., New Orleans, La.
Meetings: Monthly, 3rd Monday, Noon luncheon ($1.50), St. Charles Hotel, New Orleans.

MONTANA GEOPHYSICAL SOCIETY

(CHARTERED APRIL 12, 1954)

President: SAM MARSH, The Carter Oil Co.
1st Vice-President: JACK PETERS, Mobil Producing Co.
2nd Vice-President: M. D. WICKERHAM, Gulf Oil Corp.
Secretary-Treasurer: C. F. MOORE, Sohio Petroleum Co.
District Representative: THOMAS C. KING, Murphy Corp.
Meetings: Monthly, Second Monday.

DAKOTA GEOPHYSICAL SOCIETY

President: W. E. PHILLIPS, Stanolind Oil & Gas Co., Box 1437, Bismarck, N. D.
1st Vice-President: HUGH MCCAIN, The Atlantic Refining Co., Box 1076, Bismarck, N. D.
2nd Vice-President: QUIN HAYES, Mobil Producing Co., Box 1236, Bismarck, N. D.
Secretary-Treasurer: R. R. PHAIR, Roundup Powder Co., Box 452, Bismarck, N. D.
District Representative: HENRY NOGAMI, The Atlantic Refining Co., Box 728, Dickinson, North Dakota
Meetings: Monthly, 1st Friday, 7:30 P.M., Petroleum Club, Prince Hotel, Bismarck.

JACKSON GEOPHYSICAL SOCIETY

(CHARTERED MAY 12, 1955)

President: PHIL P. GABY, Delta Exploration Co., 206 Rankin St., Jackson, Miss.
Vice-President: FRED FORWARD, Phillips Petroleum Co., Box 3540, Jackson, Miss.
Secretary-Treasurer: W. J. ROBINSON, Sinclair Oil & Gas Co., Box 99, Jackson 5, Miss.
District Representative: BRYAN A. DUBY, The Carter Oil Co., Box 1490, Jackson, Miss.
Meetings: Monthly, during third week, 5:30–6:30 refreshments, 6:30–7:30 dinner ($2.00), technical meeting to follow, Roof Garden of Robert E. Lee Hotel, Jackson, Mississippi.

STUDENT SOCIETIES

(AFFILIATED)

COLORADO SCHOOL OF MINES SOCIETY OF STUDENT GEOPHYSICISTS

Golden, Colorado

President: RONALD E. DIEDERICH
Vice-President: ROGER C. GORE
Secretary-Treasurer: ROBERT I. BUCKNELL
Faculty Sponsor: JOHN C. HOLLISTER
Meetings: (Data not received)

GEOPHYSICAL SOCIETY OF SAINT LOUIS UNIVERSITY

President: RICHARD SNEIDER
Vice-President: GILBERT BOLLINGER
Secretary: THOMAS MCEVILLY
Treasurer: ROBERT RILEY
Faculty Moderator: REV. JAMES B. MACELWANE, S.J., Institute of Technology, 3621 Olive St., St. Louis 8, Mo.
Meetings: Monthly, 2nd Wednesday, 7:30 P.M., Meeting only, Institute of Technology.

SOCIETY OF EXPLORATION GEOPHYSICISTS HOUSTON STUDENT SECTION

President: Tom Vining, University of Houston
1st Vice-President: D. E. Miller, Rice Institute
2nd Vice-President: Eugene Green, University of Houston
Treasurer: Jack Wright, University of Houston
Secretary: D. H. Cook, University of Houston
University of Houston Sponsor: Dr. R. A. Geyer, Geophysical Service Inc., Box 6937, Houston 5, Texas
Rice Institute Sponsor: Dr. Charles B. Officer, Jr.
Meetings: (Data not received)

UNIVERSITY OF TORONTO GEOPHYSICAL SOCIETY

President: Douglas W. Allan
Vice-President: John Jamieson
Secretary-Treasurer: John E. Hogg
Faculty Sponsor: Prof. J. A. Jacobs
Meetings: Bi-weekly, alternate Thursdays, 4:00 p.m., 49 St. George St.

UNIVERSITY OF TULSA STUDENT GEOPHYSICAL SOCIETY

TRANS-PECOS STUDENT SECTION

Box 56, Texas Western College
El Paso, Texas

President: Joe H. Scales
1st Vice-President: Peter G. Gray
2nd Vice-President: Harry R. Hirsch
Secretary: John T. Sample, Jr.
Treasurer: William D. Grant
Faculty Sponsor: Wm. S. Strain
Meetings: To be announced.

PENNSYLVANIA STATE UNIVERSITY GEOPHYSICAL SOCIETY

College of Mineral Industries
University Park, Pennsylvania

President: John K. Lyon
Vice-President: Harold G. Rozelle
Secretary: James B. Imswiler
Treasurer: Donald W. Strickler
Faculty Sponsor: Dr. B. F. Howell

UNIVERSITY OF UTAH GEOPHYSICAL SOCIETY

College of Mines and Mineral Industries
Salt Lake City, Utah

President: William M. Dolan
Vice-President: J. Burlin Johnson, Jr.
Secretary: Howard L. Confer
Treasurer: Peter Mandel, Jr.
Faculty Advisor: Dr. Kenneth L. Cook
Meetings: Monthly, 1st Thursday, noon, Mines Bldg.; other special meetings to be announced

MEETINGS

NINTH ANNUAL MIDWESTERN MEETING

The Ninth Annual Midwestern Regional Meeting of the Society of Exploration Geophysicists will be held in Fort Worth, Texas, on Thursday and Friday, March 8–9, 1956, with registration on March 7, 8, 9. The headquarters for the meeting will be the Hotel Texas. The principal sponsor this year will be the Geophysical Society of Oklahoma City. Other sponsoring societies are the Geophysical Society of Tulsa, the Fort Worth Geophysical Society, the Dallas Geophysical Society, the Ark-La-Tex Geophysical Society, and the Permian Basin Geophysical Society.

The General Chairman for the convention is E. L. MOUNT, Oklahoma City. Mr. Mount has announced the names of the various committee chairmen as follows:

Program—R. M. DAVIS, Oklahoma City; Co-Chairman, F. A. ROBERTS, Oklahoma City
Finance—D. J. VAN NOSTRAND, Oklahoma City; Co-Chairman, J. H. BAADE, Oklahoma City
Housing—A. E. MCKAY, Fort Worth; Co-Chairman, J. M. COCHRANE, Oklahoma City
Arrangements—J. D. DIVELBISS, Fort Worth; Co-Chairman, W. H. SPECKHARD, Oklahoma City
Program Publication—R. D. ROBERTS, Oklahoma City; Co-Chairman, H. C. TALLEY, Oklahoma City
Entertainment—K. J. WARREN, Fort Worth; Co-Chairman, ED DEUPREE, Oklahoma City
Registration—G. A. BELL, Fort Worth; Co-Chairman, J. R. FOSTER, Oklahoma City
Publicity—B. J. BORING, Fort Worth; Co-Chairman, L. D. ERVIN, Oklahoma City

Assistance will be given these committee heads by members of all participating societies.

The theme of this Midwestern Meeting, as announced by Mr. Davis, will be "Integrated Exploration" which might be expressed mathematically as:

$$\text{EXPLORATION} = \int_{\text{Land}}^{\text{Economics and Production}} (\text{GEOLOGY} + \text{GEOPHYSICS})$$

The feature address on the domestic and foreign outlook for the oil industry will be given by a recognized authority. Included among the interesting general, technical and research papers will be a panel discussion of exploration planning with participation by representatives of management, geophysical, geological, land and legal, economics and production departments with IRA H. CRAM as Moderator.

A geological-geophysical discussion of possible Midwestern oil provinces, several sessions devoted to technical-research papers, and numerous timely papers pertaining to instrumentation and exploration techniques will help make this an outstanding convention. It is the hope that this meeting will bring forth new ideas towards the solution of the vital problem of integrated exploration.

LYNN D. ERVIN

ELEVENTH ANNUAL GULF COAST MEETING

The Gulf Coast Regional Meeting of the Society of Exploration Geophysicists is scheduled to be held at the Rice Hotel in Houston May 17 and 18, 1956, it has been announced by W. HARLAN TAYLOR, President of the Houston Section. Assisted by the Geophysical Society of Texas in San Antonio and the Southeastern Geophysical Society in New Orleans, the Houston Section will serve as host. In addition to the regular two full days of technical sessions a style show and luncheon for the ladies will be held at the Houston Club on May 18th, and the annual dinner dance that evening will be held at the Rice Hotel. Announcements of the meeting will be mailed to all members of the society in the United States.

MEMBERSHIP APPLICATIONS RECEIVED

Applications for Active membership have been received from the following candidates. This publication does not constitute an election but places the names before the membership at large, in accordance with Bylaws, Article III, Section 4. References are listed in parentheses following the name of each candidate. If any member has information bearing on the qualifications of these candidates he should send it to the President within thirty days.

APPLICATIONS FOR ACTIVE MEMBERSHIP

Derwood L. Amonett (W. B. Perry, C. J. Donnally, R. M. Rogers, J. C. Finley)
Earl B. Anderson (J. F. Rollins, E. F. McMullin, G. W. Fisher, M. C. Kelsey)
William Lloyd Audas (A. G. Nance, R. B. Haynes, K. G. McCann)
Marvin Walter Bayley (J. D. Marr, A. A. Hunzicker, F. F. Reynolds)
Andre Blanchard (F. P. Kokesh, E. G. Leonardon, E. F. Stratton, J. Bolhon)
Ralph E. Brodek (T. P. Ellsworth, J. W. Mathews, John A. Adams)
Edgardo Luis Cebrelli (Metello Cesanelli, Salvador Alvarez, Vicente Binetti)
Louis G. Chombart (Paul Charrin, James A. Ballard, Paul Lyons, E. G. Leonardon)
Wayne G. Christian (J. E. Thompson, Robert Auerbach, Robert Dyk)
Robert Purdue Clark (W. H. Courtier, A. J. Hintze, W. L. Mendenhall)
William Burl Cox (J. B. Lovejoy, Wm. D. Boone, R. H. Lang, Gordon M. Mace)
Leslie Duska (T. R. Campbell, G. J. Blundun, Harry Pearson)
Owen Counts Ellis (Lee B. Park, C. H. Hightower, Henry Nogami, Charles G. Faubion)
Sidney Hatchl (Harold Frank, Gerry Bilbert, H. A. Sears)
Robert M. Jemison, Jr. (G. A. Burton, D. D. Utterback, H. C. Petersen)
J. G. Joyce (R. B. Wilcoxon, H. F. Sagoci, R. D. Terry)
William Crowe Kellogg (F. Woods Hinrichs, R. Maurice Tripp, C. A. Heiland)
Kenneth F. Keller (P. E. Nash, R. R. Rosenkranz, D. R. Doybns, W. S. Hawes)
E. D. Klinger (T. O. Harkness, G. W. Westby, Herbert Schlundt)
George Lane Laird (H. M. Dawson, T. L. Allen, G. L. Barksdale)
Edward T. Laurent (A. B. Bryan, Paul Lyons, W. W. Clark, George E. Wagoner)
Robert W. Leeder (J. E. McGee, David K. Kirk, L. F. Melchoir)
William Alfred Linton (C. W. Blakey, J. L. Friendly, E. H. Weltsch)
John Warner Loven (W. A. Matthews, Frank Ellsworth, J. M. Desmond)
James A. McCool (H. R. Imle, G. E. Olson, J. P. Duncan)
Raymond Ustick McKinney (R. M. Bradley, A. F. Beck, W. G. Green, W. E. Pugh)
Dennis C. Meyer (R. C. Clark, H. L. Copeland, W. E. Franks, R. F. Weichert)
Eugene P. Neal (R. W. Mossman, T. A. Manhart, W. W. Butler)
Arthur M. Noon (D. G. Van Nostrand, R. C. Herron, W. B. Robinson)
Gustavo Bello Orta (Manuel Alvarez, Jr., Antonio G. Rojas, K. R. Beeman, H. Gerard)
Eugene Dominic Reinerio (W. B. Heroy, Jr., J. D. Perryman, D. M. Steel, G. E. Seiler)
Richard A. Smyrl (W. L. Crawford, Thomas L. Allen, Paul T. Rumsey)
William H. Strickland (C. A. Wood, R. F. Christy, J. D. Delbridge, R. C. Kendall)
Maurice Pierre Tixier (E. G. Leonardon, F. P. Kokesh, Paul Weaver)
Marion Orville Turner (K. C. Thompson, J. W. Fishback, F. H. Hammons)
John Colin Underhill (H. R. Ellard, G. C. Agnew, A. S. Gibson)

TRANSFER TO ACTIVE MEMBERSHIP

Gerrit Baker (G. Kok, H. H. Brons, B. Baars)
Charles P. Bragg (R. P. Radebaugh, R. W. Carter, Neil Mann, Fred Agnich)
Sam L. Evans (R. W. Carter, Neil Mann, Fred Agnich, R. P. Radebaugh)
DeWitt Pierce Fleming (George Augustat, Dwayne L. Pretzer, Ewin D. Gaby)

C. Jerrold Frankovitch (M. D. Bradford, S. O. Patterson, E. F. K. Zarudzki)
Debkumar Ganguli (J. B. Macelwane, Carl Kisslinger, V. J. Blum)
John Humphreys Hoke (Sam Zimerman, Burt Beverly, I. J. Reed, O. A. Seager)
Edward Hadley Holland (V. G. Winston, G. E. Fritts, A. G. Morton)
George Preston Howard (A. B. Winter, Dean Batchelder, Horace Ray)
Paul E. Howe (W. B. Lee, Jr., L. P. Bristley, J. E. McGee)
Russell L. Long (K. C. Thompson, M. B. Widess, Karl Dyk)
Raymond Morris Low (W. W. Butler, E. S. Sherar, J. F. Freel)
Nelson Erroll Lurton, Jr. (G. C. Howard, H. A. Morriss, Jr., G. J. Baker)
Donald Garrett McWilliams (J. D. Marr, A. A. Hunzicker, F. F. Reynolds)
Robert Allen Newton (O. D. Brooks, J. P. Leonard, Sam B. Holland)
John C. Peffer (F. R. Reeves, J. C. Menefee, O. H. Armstrong)
Robert Everet Plumb (Robert J. Wells, Richard W. Shoemaker, Maurice Sklar)
Robert E. Sanford (Homer I. Henderson, T. R. Shugart, W. W. Newton)
George B. Seeburger (F. B. Leedy, Neal Clayton, R. H. Pohly)
William Emmett Shafer (A. V. Lewis, W. R. Fillippone, John Sloat)
E. B. Wasson (Robert Dyk, J. A. Harris, M. G. Frey)
John F. Weyer (R. F. Aldredge, Thomas Oritz, Glenn E. Blackledge)
Reymond W. Wilkinson (L. W. Cobena, Merrill Smith, E. H. Shannon, B. H. Treybig, Jr.)
Ocie Geron Williams (C. H. Hightower, Hugh McCain, Jr., Roy Floyd)

SOCIETY OF EXPLORATION GEOPHYSICISTS

ANNUAL REPORT

1954–1955

Officers and committee members who retired at the close of the Twenty-Fifth Annual Meeting served terms of at least eighteen months, a six-month extension which resulted from moving the date of the Annual meeting from spring to fall. In recognition of the added burden thus placed upon these members we owe them an extra measure of gratitude for the fine spirit in which they served and accomplished so much.

The efforts of these members and the cooperation of their companies have made possible the continued rapid growth of the SEG in numbers and in service to our science. Space does not permit acknowledgment here, but the Society owes no less a debt of gratitude to the many other members who have devoted their time and talents during the past year and a half without public recognition.

It is a privilege to announce the election of the following officers whose terms began at the close of the Twenty-Fifth Annual Meeting.

President: R. C. DUNLAP, JR., Geophysical Service Inc., Dallas, Texas.
Vice-President: DAVE P. CARLTON, recently retired from Humble Oil and Refining Co., Houston, Texas
Secretary-Treasurer: GEORGE A. GRIMM, Tide Water Associated Oil Co., Midland, Texas
Editor: NORMAN RICKER, The Carter Oil Co., Tulsa, Oklahoma

Dr. Ricker will serve for two years as Editor. Mr. Dunlap will serve on the Executive Committee for one year as President and one year as Past-President.

A special word of thanks is due the other nominees:

For President: J. E. McGee, Gulf Oil Corporation, Houston, Texas
For Vice-President: Bart W. Sorge, United Geophyical Coproration, Pasadena, California
For Secretary-Treasurer: John A. Lester, Magnolia Petroleum Co., Dallas, Texas
For Editor: T. A. Elkins, Gulf Research and Development Co., Pittsburgh, Pennsylvania

That they are held in high esteem is evidenced by the fact that so many of their fellow members voted for them.

The Society's operations are performed primarily by standing and special committees under the direction of the Executive Committee, which is in turn responsible to the Council. A complete summary of operations during the past eighteen months is therefore given in the committee reports.

The report of the Standing Committee on Education is published in October 1955 GEOPHYSICS. Because the Standing Committee on Radio Facilities was not called upon in its advisory capacity to the petroleum industry, it made no report. The report of the Standing Committee on Geophysical Activity was made during the Annual Meeting. The final report of the Special Committee on Code of Ethics was published in October 1954 GEOPHYSICS.

PAUL L. LYONS, *President*

REPORT OF VICE-PRESIDENT

Your Vice-President attended all Executive Committee meetings scheduled by President Lyons to conduct Society business He was appointed New York Chairman for SEG by Mr. G M. Knebel, General Manager of the Oil Finders Convention. To aid in the many details of program and arrangements, Mr. Ralph B. Ross was appointed Program Chairman, and Mr. Harvey Cash was appointed Arrangements Chairman. The result of their efforts was outstanding as indicated by the success of the New York meeting. The meeting had a total attendance of 3,784, 550 of which were SEG members. The meeting was financially sound; however, final auditing figures are not available at this time. Cooperation of the three societies left nothing to be desired. Even though SEG had few members in New York City, their diligent and sincere work helped Mr. Knebel and his chairmen considerably.

We were indeed appreciative for the large number of papers submitted making it possible to select sufficient good papers to present an organized program. We wish to express our appreciation to the many authors whose work made possible the program.

Your Vice-President has met on several occasions with Mr. Robert Dyk, General Chairman of the Denver meeting, and his program committee.

The Program and Arrangements Committee is charged with handling many details, and I wish to express my appreciation for the help of the committeemen which consists of all District Representatives and a few members-at-large. This has been a long eighteen months, but I will always be appreciative of the opportunity afforded me by the membership to serve the Society in this capacity.

ROY F. BENNETT, *Vice-President*

REPORT OF THE SECRETARY-TREASURER

The term of the Secretary-Treasurer and other officers elect of 1954 extended from April 12, 1954 to October 3, 1955, the period covered in this report.

Most of the problems discussed and handled by the Executive Committee arose from changing conditions brought about by the rapid growth of the society in both membership and activities.

A total of 105 Executive Orders were issued between April 12, 1954 and August 29, 1955. Of these 89 were concerned with membership applications, change in membership status, or resignations. Others were as follows:

No. 465—April 22, 1954—Authorized purchase of Addressograph and other office equipment.

No. 466—April 29, 1954—Authorized Acceptance of the Association of Geology Teachers as a member of the American Geological Institute.

No. 467—April 29, 1954—Authorized the Business Manager to attend the 1954 Annual Meeting of the Council of Engineering Society Secretaries, May 20–21, 1954, Detroit, Michigan.

No. 476—Acceptance of Tulsa Geological Society to membership in the American Geological Institute.

No. 479—June 10, 1954—Authorized engagement of Lybrand, Ross Bros. & Montgomery to conduct audit.

No. 484—July, 6 1954—Authorized approval of the request of New York State Geological Association to affiliate with AGI.

No. 496—September 7, 1954—Established price for the Cumulative Index.

No. 517—January 14, 1955—Approved Christmas Bonus for the four employees of the Society.

No. 524A—February 11, 1955—Designated the 10 Annual Gulf Coast Meeting a Regional Meeting of the Society of Exploration Geophysicists.

No. 536—April 4, 1955—Approved General License GTDP on all mail outside the United States and Canada.

No. 537—April 4, 1955—Approved affiliation of Trans Pecos Geophysical Society of Texas Western College as student section of SEG.

No. 540—April 12, 1955—Approved affiliation of Pennsylvania State University Geophysical Society as student section of SEG.

No. 543—April 26, 1955—Approved affiliation of the Jackson Geophysical Society as the Jackson Section of the Society of Exploration Geophysicists.

No. 545—May 6, 1955—Authorized publication of reprints of Volumes I, II and III, of GEOPHYSICS.

No. 549—June 1, 1955—Approved affiliation with Utah University Geophysical Society as student section of SEG.

No. 558—August 17, 1955—Approved election of Cecil H. Green, Paul Weaver and J. B. Macelwane to honorary membership of SEG.

Meetings attended by Executive Committee members were: A council meeting on April 12, 1954; a recall meeting of this recessed session on July 16, 1954; and Executive Committee meetings of

April 14, 1954; June 16, 1954; November 18, 1954; March 27, 1955; and March 31, 1955.

Major actions taken by the Council and Executive Group are tabulated by meeting below:

Annual Joint Council Meeting—April 12, 1954

1) Unanimous approval was given to acts and actions of Executive Committee of the year of 1953–54 with specific endorsement of the decision of Executive Committee to withdraw from the Joint Annual Meeting with the AAPG and SEPM.

2) Resolved that officers elected for the year 1954–55 would hold those offices until the Annual Joint Council Meeting of the SEG in the fall of 1955.

3) Approved changes in By-Laws as published in the January 1954 issue of GEOPHYSICS which provided the necessary changes in wording and dates to hold a separate meeting of SEG in the fall of 1955.

4) Approved the educational brochure and directed the Executive Committee to proceed with printing and distribution.

5) Approved in substance certain changes in the Bylaws designed to facilitate the handling of membership applications.

6) Meeting recessed subject to recall instead of adjourned so that uncompleted business could be transacted after proposed changes in By-Laws were published in GEOPHYSICS.

Recall Session of Annual Joint Council Meeting—June 16, 1954

1) Approved of changes in By-Laws regarding handling of membership applications and suspensions as published in July, 1954 issue of GEOPHYSICS.

Executive Committee Meeting—April 14, 1954

1) Recommended a complete study of the Constitution and By-Laws by the Committee on Constitution and By-Laws with the intent of making such changes as are necessary to provide for handling of present day problems brought about by increased membership and activities.

Executive Committee Meeting—June 16, 1954

1) Chose New Orleans as site for 1956 National Convention.

2) Officially adopted a policy with respect to acceptance or refusal of papers for publication in GEOPHYSICS (pages 855–56, October, 1954 issue of GEOPHYSICS).

3) Established prices for sale of individual copies of the Educational Brochure.

Executive Committee Meeting—November 18, 1954

1) Dallas chosen as convention site in 1957.

2) Accepted proposal from local sections sponsoring the regional meeting in Dallas and Ft. Worth that no meeting be held in 1955, and that next meeting be held in the spring of 1956.

3) Approved the preparation and presentation of silver anniversary certificates to charter members at the annual meeting in Denver, 1955.

4) Announced the formation of Society of Exploration Geophysicists Research Committee.

5) Made changes in discount rates to eliminate discounts to government bureaus.

6) Proposed that SEG determine and publish a "Code of Ethics" for geophysicists.

Executive Committee Meeting—March 27, 1955

1) Recommended to the Committee on Constitution and By-Laws that provisions be made for the creation of a Standing Committee for the Publication of Geophysical Case Histories.

2) Approved contribution of $1,000.00 to AGI for the fiscal year of 1955–56.

3) Requested the Committee on Constitution and By-Laws to provide for a $.50 per year increase in dues for all categories of membership.

4) Raised the price of back issues to $2.00 to members and $2.50 to non-members.

5) Requested that the Educational Brochure be mailed to high schools again in September 1955.

Executive Committee Meeting—March 31, 1955

1) Approved the purchase of group insurance for business office employees provided they could qualify for joint participation with the AAPG business office.

2) Permission given AGI to provide their membership list on a rental basis.

The fiscal year for SEG was changed from a calendar year to the period from July 1 to June 30 in order that an incoming treasurer taking office in the fall could have some control over the year's operations for which he was responsible. For this reason it is necessary to present a résumé of income for the first six months of 1954 along with that of the fiscal year extending from July 1, 1954 through June 30, 1955.

SOCIETY OF EXPLORATION GEOPHYSICISTS

Comparative Statements of Net Income, 1952–1955
Estimated Net Income for 1955–1956

	1952	1953	1954 1st 6 Mo.	1954–1955	1955–1956 Estimate
Income					
Membership dues	$24,403.00	$30,281.50	$15,701.00	$34,413.60	$ 37,000.00
Geophysics	28,440.57	34,266.86	18,215.86	38,061.26	41,000.00
Geophysical Case Histories	848.00	1,116.60	324.95	1,859.50	12,000.00
Cumulative Index	38.00	16.20	—	—	5,000.00
Careers in Exploration Geophysics	—	—	—	13,230.39	—
Commissions received	1,295.28	—	448.15	680.26	600.00
Interest received	337.11	360.43	171.71	314.93	400.00
Conventions	—	—	—	—	5,000.00
Other	1,428.88	6,246.10	407.44	1,434.54	1,000.00
Total Income	$56,790.84	$72,287.69	$35,269.11	$89,994.48	$102,000.00
Expenses					
Operating expenses	$31,151.69	$46,971.91	$20,048.87	$43,777.61	$ 48,000.00
Publications:					
Geophysics	24,509.28	24,785.11	12,805.64	25,829.51	30,000.00
Geophysical Case Histories Vol. II	—	—	—	—	12,000.00*
Cumulative Index	—	—	—	—	5,000.00*
Careers in Exploration Geophysics	—	—	—	15,215.87	2,000.00[1]
Total Expenses	$55,660.97	$71,757.02	$32,854.51	$84,822.99	$ 97,000.00
Net Income	$ 1,129.87	$ 530.67	$ 2,414.60	$ 5,171.49	$ 5,000.00

* Because all profits on sale of special publications must be "ploughed back" to reduce inventory valuation during the first year of sales, there will be no profit on Case Histories and Cumulative Index—unless sales during 1955–1956 fiscal year exceed total publication costs.

[1] The second mailing of "Careers" to high schools will cost about $2,000.

During the current fiscal year of 1955–56 the affairs of SEG will approach or exceed a $100,000.00 a year business. No business man or group of business men should attempt to run an organization wherein the differential between making a profit and having a deficit is of the order of 5% of income when the individual size of the projects undertaken is of the order of 10% of total income or expenditures. To protect the reputation of its elective officers and business manager, the SEG must provide for an increased income of approximately $10,000 per year (considering the present operating level) by a combination of the following or similar methods:

a) Increased dues
b) Convention income
c) Increased sale of special publications
d) Pressure sale of items in inventory
e) Rental of membership list and mailing service
f) Other outside activities

Unless this increase in income is achieved, future executive committees must at all times examine the proposed projects in the light of commercial success or failure regardless of the other merits of the project.

The Secretary-Treasurer wishes to express his appreciation for the aid and cooperation he has received from all concerned; the Executive Committee, the Business Office Committee headed by Stefan Von Croy, the secretaries of all the local societies, and last but not least, the Business Manager and his complete office staff who have helped transform a burdensome task into a pleasant one.

H. M. THRALLS

REPORT OF AUDITORS

To the Executive Committee,
Society of Exploration Geophysicists.

We have examined the balance sheet of the SOCIETY OF EXPLORATION GEOPHYSICISTS as of June 30, 1954 and the related statement of income for the six-month period then ended. Our examination was made in accordance with generally accepted auditing standards, and accordingly included such tests of the accounting records and such other auditing procedures as we considered necessary in the circumstances except that, in accordance with the terms of our engagement, we did not obtain confirmation of the accounts receivable from members and others.

In our opinion, subject to the above comments relating to the confirmation of accounts receivable, the accompanying balance sheet and related statement of income present fairly the financial position of the SOCIETY OF EXPLORATION GEOPHYSICISTS at June 30, 1954 and the results of its operations for the six-month period then ended, in conformity with generally accepted accounting principles applied on a basis consistent with that of the preceding year.

LYBRAND, ROSS BROS. & MONTGOMERY
CERTIFIED PUBLIC ACCOUNTANTS

Tulsa, Oklahoma
July 29, 1954

EXHIBIT "A"

SOCIETY OF EXPLORATION GEOPHYSICISTS
BALANCE SHEET—JUNE 30, 1954

ASSETS

Current Assets:		
Cash		$24,214.96
Accounts receivable:		
Membership dues	$ 2,800.50	
Advertising and other	1,897.51	
	$ 4,698.01	
Less: Allowance for doubtful accounts	1,626.09	3,071.92
Inventories (Notes A and B):		
GEOPHYSICS	$ 2,275.00	
Publications-in-progress	14,346.82	16,621.82
TOTAL CURRENT ASSETS		$43,908.70
Investments:		
United States Savings Bonds, at cost	$14,040.00	
Stock of Container Corporation of America	466.75	14,506.75
Fixed Assets:		
Office furniture and fixtures	$11,444.91	
Less: Allowance for depreciation	2,222.46	9,222.45
Prepaid Expenses and Deferred Charges:		
Prepaid postage, insurance and other	$ 1,841.87	
Deferred agency commissions and discounts	515.38	2,357.25
		$69,995.15

LIABILITIES AND MEMBERS' EQUITY

Current Liabilities:		
Accounts payable (Notes A and B)		$20,463.52
Deferred Income:		
Membership dues paid in advance	$16,345.27	
Subscriptions to and advertising in GEOPHYSICS paid in advance	3,809.31	20,154.58
Members' Equity:		
Balance, December 31, 1953	$26,962.45	
Net income for the period (Exhibit B)	2,414.60	
BALANCE, JUNE 30, 1954		$29,377.05
		$69,995.15

The accompanying notes are an integral part of the financial statements.

EXHIBIT "B"

SOCIETY OF EXPLORATION GEOPHYSICISTS
STATEMENT OF INCOME

FOR THE SIX-MONTH PERIOD ENDED JUNE 30, 1954

Income from Operations:		
Membership dues		$15,701.00
GEOPHYSICS Magazine, etc:		
Advertising	$14,221.11	
Subscriptions	3,362.88	
Back numbers	407.85	
Microcards of back numbers	91.07	
Reprints	491.12	
Index of wells	32.50	
Discounts allowed	(390.67)	18,215.86
Geophysical Case Histories, Vol. I		324.95
Commissions on sale of books published by others		448.15
Miscellaneous:		
Interest and dividends received	$ 171.71	
Other	407.44	579.15
		$35,269.11
Publication Costs and Expenses:		
Publication costs—(Schedule I)	$12,805.64	
Operating expenses—(Schedule II)	21,326.15	34,131.79
Net income from operations		$ 1,137.32
Safety Committee Operations:		
Income from sale of posters and subscriptions to Safety Committee publications	$ 2,981.52	
Expenses—Cost of printing and miscellaneous expenses	1,479.82	
Net income from Safety Committee operations		$ 1,501.70
Distinguished Lecture Tours:		
Income from lecture tours	$ 322.00	
Expenses of lecture tours	546.42	
Net loss from lecture tours		(224.42)
TOTAL NET INCOME (Exhibit "A")		$ 2,414.60

The accompanying notes are an integral part of the financial statements.

SOCIETY OF EXPLORATION GEOPHYSICISTS
PUBLICATION COSTS AND OPERATING EXPENSES

FOR THE SIX-MONTH PERIOD ENDED JUNE 30, 1954

Publication Costs—Schedule I

GEOPHYSICS, Volume XVIX:	*Copies*	*Amount*
No. 1, 272 pages	6,000	$ 5,791.95
No. 2, 384 pages	6,000	5,890.76
		$11,682.71
Less: Increase in inventory at June 30, 1954 (Note A)		1,448.00
		$10,234.71
Microcards of GEOPHYSICS (back numbers)		557.75
Reprints		342.92
Membership lists		1,670.26
		$12,805.64

Operating Expenses—Schedule II

Salaries:	
Business manager	$ 4,200.00
Business office employees	3,640.00
Commissions:	
Advertising—business manager	711.06
Advertising—agencies	2,024.34
Subscriptions—agencies	248.08
Office rent	1,302.00
Stationery and office supplies	2,941.69
Telephone and telegraph	375.36
Postage	1,201.21
Advertising expense	90.30
Traveling expense	157.28
Depreciation of office equipment	630.41
Provision for bad debts	1,716.61
Federal insurance contributions tax	157.03
Audit expense	664.15
Regional meetings expense	29.43
Purchase of books published by others	510.35
Loss on sale of fixed assets	6.31
Miscellaneous expense	720.54
	$21,326.15

The accompanying notes are an integral part of the financial statements.

SOCIETY OF EXPLORATION GEOPHYSICISTS
NOTES TO FINANCIAL STATEMENTS

JUNE 30, 1954

NOTES:

(A) Following the practice started in 1953, the quarterly publications of GEOPHYSICS published in 1953 and subsequent years are to be valued at their respective selling prices to members and included in the balance sheets. At June 30, 1954, the amount so included was $2,275.

The publications-in-progress includes the cost to date of printing a Cumulative Index ($1,354.66) and the cost of printing the publication "Careers in Exploration Geophysics" ($12,670.71) which will be distributed in July, 1954.

The inventories of back issues of GEOPHYSICS, issued prior to 1953, and of other publications, are estimated at their respective selling prices to be approximately $16,000 which, in accordance with practices of prior years, have not been reflected in the balance sheet at June 30, 1954.

(B) Included in accounts payable is the billing for printing of "Careers of Exploration Geophysics" ($12,670.71) and the billing for addressograph equipment ($3,908.04) which is in the process of installation at the Society's business office in Tulsa.

To the Executive Committee,
Society of Exploration Geophysicists

We have examined the balance sheet of the SOCIETY OF EXPLORATION GEOPHYSICISTS as of June 30, 1955 and the related statement of income for the year then ended. Our examination was made in accordance with generally accepted auditing standards, and accordingly included such tests of the accounting records and such other auditing procedures as we considered necessary in the circumstances except that, in accordance with the terms of our engagement, we did not obtain confirmation of the accounts receivable from members and others.

In our opinion, subject to the above comments relating to the confirmation of accounts receivable the accompanying balance sheet and related statement of income present fairly the financial position of the SOCIETY OF EXPLORATION GEOPHYSICISTS at June 30, 1955 and the results of its operations for the year then ended, in conformity with generally accepted accounting principles applied on a basis consistent with that of the preceding year.

LYBRAND, ROSS BROS. & MONTGOMERY
CERTIFIED PUBLIC ACCOUNTANTS

Tulsa, Oklahoma,
July 15, 1955

EXHIBIT "A"

SOCIETY OF EXPLORATION GEOPHYSICISTS
BALANCE SHEET—JUNE 30, 1955

ASSETS

Current Assets:		
Cash		$22,522.41
Accounts receivable:		
Membership dues	$ 1,810.11	
Advertising and other	5,479.73	
	$ 7,289.84	
Less allowance for doubtful accounts	1,200.00	6,089.84
Inventories (Note A):		
GEOPHYSICS	$ 5,031.00	
Cumulative index	2,318.65	7,349.65
TOTAL CURRENT ASSETS		$35,961.90
Investments:		
United States Savings Bonds, at cost	$14,040.00	
Stock of Container Corporation of America	466.75	14,506.75
Fixed Assets:		
Office furniture and fixtures	$11,560.83	
Less allowance for depreciation	3,747.49	7,813.34
Prepaid Expenses:		
Prepaid postage, insurance and other		860.99
		$59,142.98

LIABILITIES AND MEMBERS' EQUITY

Current Liabilities:		
Accounts payable		$ 1,058.01
Deferred Income:		
Membership dues paid in advance	$18,278.88	
Subscriptions to and advertising in GEOPHYSICS paid in advance	4,165.75	
Advance sales of special publications	1,091.80	23,536.43
Contingent Liabilities (Note B)		
Members' Equity:		
Balance, June 30, 1954	$29,377.05	
Net income for the year (Exhibit B)	5,171.49	
BALANCE, JUNE 30, 1955		34,548.54
		$59,142.98

The accompanying notes are an integral part of the financial statements.

EXHIBIT "B"

SOCIETY OF EXPLORATION GEOPHYSICISTS
STATEMENT OF INCOME

FOR THE YEAR ENDED JUNE 30, 1955

Income from Operations:		
Membership dues		$34,413.60
GEOPHYSICS Magazine, etc.:		
Advertising	$29,422.78	
Subscriptions	7,100.57	
Back numbers	1,560.16	
Microcards of back numbers	232.90	
Reprints	767.93	
Index of wells	57.50	
Discounts allowed	(1,080.58)	38,061.26
Geophysical Case Histories, Vol. I		1,859.50
Vocational Guidance Brochures		13,230.39
Commissions:		
Sales of books published by others	$ 578.26	
Sales of microcard readers	102.00	680.26
Miscellaneous:		
Interest	$ 314.93	
Other	1,434.54	1,749.47
		$89,994.48
Publication Costs and Expenses:		
Publication costs—(Schedule I)	$41,045.38	
Operating expenses—(Schedule II)	42,149.65	83,195.03
Net income from operations		$ 6,799.45
Safety Committee Operations:		
Income from sale of posters and subscriptions to Safety Committee publications	$ 1,026.85	
Expenses—cost of printing and miscellaneous expenses	2,385.58	
Net loss from Safety Committee operations		(1,358.73)
Distinguished Lecture Tours:		
Income from lecture tours	$ 1,347.00	
Expenses of lecture tours	1,616.23	
Net loss from lecture tours		(269.23)
TOTAL NET INCOME—(Exhibit A)		$ 5,171.49

The accompanying notes are an integral part of the financial statements.

SOCIETY OF EXPLORATION GEOPHYSICISTS
PUBLICATION COSTS AND OPERATING EXPENSES

FOR THE YEAR ENDED JUNE 30, 1955

Publication Costs—Schedule I

	Copies		*Amount*
GEOPHYSICS, Volume XIX:			
No. 3, 344 pages	6,000		$ 6,832.58
No. 4, 312 pages	6,000		6,587.00
GEOPHYSICS, Volume XX:			
No. 1, 296 pages	6,500		6,003.56
No. 2, 374 pages	6,500	$6,119.78	
Membership list		2,164.19	8,283.97
			$27,707.11
Less increase in inventory at June 30, 1955			2,756.00
			$24,951.11
Bound volumes			57.48
Reprints			820.92
Vocational Guidance Brochure			15,215.87
			$41,045.38

Operating Expenses—Schedule II

Salaries:	
Business manager	$ 8,400.00
Business office employees	8,300.60
Commissions:	
Advertising—business manager	1,471.14
Advertising—agencies	4,374.14
Subscriptions—agencies	790.12
Office rent	2,604.00
Stationery and office supplies	4,427.35
Telephone and telegraph	558.28
Postage	3,925.98
Advertising expense	395.56
Traveling expense	323.59
Depreciation of office equipment	1,525.03
Provision for bad debts	1,528.81
Federal insurance contributions tax	238.37
Audit expense	252.52
Regional meeting expense	6.23
Purchase of books published by others	592.49
Contribution to AGI	1,000.00
Other	1,435.44
	$42,149.65

The accompanying notes are an integral part of the financial statements.

SOCIETY OF EXPLORATION GEOPHYSICISTS
NOTES TO FINANCIAL STATEMENTS

JUNE 30, 1955

NOTES

(A) Following the practice started in 1953, the quarterly publications of GEOPHYSICS published in 1953 and subsequent years are included in the balance sheet at $1 a copy which is approximate cost and lower than market.

The inventory of the Cumulative Index, published in fiscal year 1955, is included in the balance sheet only to the extent of the unrecovered cost of the publication.

The inventories of back issues of "GEOPHYSICS," issued prior to 1953, and of other publications, are estimated at their respective selling prices to be approximately $15,000. In accordance with practices of prior years, these items have not been reflected in the balance sheet at June 30, 1955.

(B) The Society has placed orders for the printing of "Geophysical Case Histories, Volume II" and the reprinting of "GEOPHYSICS, Volumes I, II and III." The estimated cost of these publications is $15,000 and anticipated completion date is August 30, 1955.

REPORT OF THE EDITOR

With this meeting, the present Editor completes a 30-month term of office which began at the close of the 1953 Annual Meeting in Houston. Significant editorial activities during the first twelve months of this period were reported on in April, 1954 at the Annual Meeting in St Louis. This report is devoted mainly to developments of the past 18 months.

A shortage, noted in the April, 1954 report, of acceptable manuscript material resulted in a precariously small backlog of papers for GEOPHYSICS all during the first year of my term. This shortage continued until April of this year; since then a substantial improvement has been noted. An unusually large number of high-quality manuscripts was submitted during the past six months and my successor, Dr. Ricker, should be able to begin his term as Editor with a comfortable backlog.

The six issues of GEOPHYSICS from July, 1954 to October, 1955 contained 70 technical papers totalling 1,020 pages in length. Other technical material in these six issues took up 138 pages for a total of 1,158 technical pages. Table I presents some statistics for each of these issues and compares averages during this period with averages for two previous periods since 1952.

TABLE I

TECHNICAL MATERIAL PUBLISHED IN GEOPHYSICS
1952–1955

	No. Technical and Non-Technical Papers	No. Pages of Technical and Non-Technical Papers	Av. Length of Each Paper, p.	No. Pages Other Technical Material	Total No. Technical Pages
July, 1954	14	171	12	40	211
October, 1954	11	180	16	15	195
January, 1955	11	162	15	20	182
April, 1955	9	120	13	23	143
July, 1955	12	185	15	22	207
October, 1955	13	202	15.5	18	220
Average, six issues above	11.5	170	14.5	23	192
Average, July, 1953–April, 1954	11	166	14.8	18.5	184
Average, April, 1952–January, 1953	14	213	15	18	231

The average amount of technical material published per issue during the past 18 months is slightly greater than it was during the preceding year. This average is still far below that during the year from April, 1952 to January, 1953 which represents an all-time peak for the Society in literary productivity. The average length of each paper has remained remarkably constant at about 15 pages during the past few years.

Since April, 1953, a total of 187 manuscripts have been submitted to GEOPHYSICS. Seven of these have been short items which were printed with only cursory screening as "Letters to the Editor" in the "Discussions and Communications" section. Of the others, 113 have been printed or are in press for the October, 1955 issue, 27 have been rejected, and 39 are still "in the mill." Considering only the papers on which final action has been taken, 27 out of 140 papers, or about 19% have been rejected.

The distribution of subject matter in the 187 papers submitted during this period is as follows:

Seismic techniques and operations	30
Seismic theory	28
Seismic experiments	28
Gravity prospecting	25
General (non-technical)	24
Electrical prospecting	20
Magnetic prospecting	7
Mining geophysics	7
Miscellaneous technical (geothermals, microseisms, geological, etc.)	7
Case histories	6

According to these figures, there is some disparity in the workloads of the various associate editors. For example, the Associate Editor for Seismic Theory and Fundamentals would have handled 56 manuscripts (28 on theory and 28 on experimental work) if this position had been in existence throughout the period concerned. This is almost twice as many manuscripts as any other associate editor would have processed. It therefore may be desirable to redistribute this load in the future among two associate editors, one for seismic theory and one for seismic experiments.

Beginning with the July, 1954 issue a new front cover design, incorporating the Society's crest, was adopted for GEOPHYSICS after approval by the Executive Committee. At the same time, a new procedure was inaugurated in separating technical papers from non-technical papers in each issue.

In June, 1955 the Society's third Cumulative Index was published as a separate volume 316 pages long, the index provides a convenient key to all papers, reviews, and patent abstracts which have appeared in GEOPHYSICS and in the Society's special publications. The subject index is particularly thorough and well organized, thanks to the conscientious efforts of Dr. Kenneth L. Cook, of the University of Utah, who was responsible for its compilation. Colin C. Campebll, the Society's Business Manager, supervised the production of the Index in a highly efficient manner.

The Society's policy regarding publication of technical papers presented at its meetings was revised by the Executive Committee during the past year and a statement of the new policy appears in the October, 1954 issue of GEOPHYSICS (p. 855–856). The Society now claims the first right to publish papers given orally at its meetings unless special arrangements are made in advance with the program chairman of the meeting concerned. Papers presented at Society meetings may not ordinarily be submitted to other journals unless the Editor relinquishes them for this purpose or does not accept them for publication in GEOPHYSICS.

At its meeting in March, 1955 the Executive Committee discussed the possible sponsorship by the Society of additional special publications. It was agreed that new publications should be encouraged both as a service to the geophysical profession and also as a possible source of income for the Society. The publications Committee was asked to take on the responsibility of recommending special publications to the Society from time to time. It is likely that more specific recommendations will be presented for early consideration by the Executive Committee.

The Editor wishes to express his appreciation to the many persons who assisted him in the execution of his duties. The five Associate Editors, Dr. Norman Ricker, Thomas A. Elkins, Dr. L. Y.

Faust, Victor Vacquier, and Dr. Irwin Roman, have been most diligent in handling the evaluation of manuscripts in their respective departments. Dr. John P. Woods and the four other members of his publications committee have been very helpful in advising the Editor on numerous policy problems that have arisen during his term. Dr. Nelson Steenland and his Reviews Committee have kept the readers of GEOPHYSICS well informed on the current geophysical literature through the excellent reviews they have prepared or solicited. Mr. O. F. Ritzmann has continued his faithful coverage of geophysical patents for GEOPHYSICS. This is Mr. Ritzmann's fourteenth year of continuous service in compiling patent abstracts for the Society. Mr. Paul L. Lyons, SEG President, and the other members of the Executive Committee have been most cooperative in all matters pertaining to publications and it has been a pleasure to work with them for the past 18 months. Colin C. Campbell, the Society's Business Manager, has been most unselfish in his willingness to help the Editor in every way.

The technical personnel of the Atlantic Refining Company's Geophysical Laboratory have relieved the Editor of a heavy burden of work by reading page proofs for all issues of GEOPHYSICS; he is most grateful for this assistance. Mrs. Margaret Bryson of the Magnolia Petroleum Company has been highly cooperative in handling a large volume of correspondence and filing. The Editor wishes to express his appreciation to the Magnolia management for making her services available for this purpose. Finally, acknowledgment is made to more than 100 necessarily anonymous referees for their important part in maintaining a high level of quality in the papers appearing in GEOPHYSICS.

Of all the officers of the Society, the Editor is the only one who has a tangible product to show for his efforts after his term is over. For this reason, I consider the editorship to be the most rewarding office the Society has to offer and I have very much appreciated the opportunity of holding it during the past two and one-half years.

MILTON B. DOBRIN, *Editor*

September 9, 1955

REPORT OF THE TWENTY-FIFTH ANNUAL MEETING COMMITTEE

A committee to arrange for the 25th annual meeting of the Society to be held at the Shirley-Savoy Hotel in Denver, October 3–6, 1955, was organized by Mr. Robert Dyk, General Chairman, the first of the year. Members of this committee met informally at frequent intervals during the first part of the year. Formal meetings with representatives of all sub-committees were held July 25, August 10, and August 23.

Mr. Colin Campbell attended the meeting of August 10, during a visit to Denver to assist in the arrangements and to coordinate the activities of the committee with SEG headquarters. Colin Campbell's visit proved very helpful to the committee and was greatly appreciated by all. At that time arrangements were made for a return visit by Colin Campbell the first part of September to assist in a dry-run on the registration procedure and the set-up of equipment in the meeting room.

Because the meeting is to be the twenty-fifth annual meeting, it was decided that the program would honor the Past Presidents and Charter Members of the Society. A commemorative program booklet was designed which includes an excellent résumé of the history of geophysics and the SEG by out-going-president, Paul Lyons. The program booklet also includes pictures and biographical sketches of the three men being awarded Honorary Memberships and pictures and biographical sketches of the speakers with abstracts of their papers.

Mr. Marvin Romberg, Program Chairman, reports that with the exception of a tentatively-scheduled address by Mr. Herbert Hoover, Jr., the program is committed and complete. Mr. Hoover has stated that he will deliver an address if he is able to leave Washington, D. C., at that time. The featured spot in the general session on Tuesday morning, October 4, will be kept open in the hope that Mr. Hoover will be able to appear.

The technical sessions will be held Monday afternoon, October 3; Tuesday afternoon, October 4; Wednesday morning, afternoon, and evening, October 5; and Thursday morning, afternoon, and evening, October 6. All sessions will be held in the Lincoln Room of the Shirley-Savoy Hotel.

Through the courtesy and cooperation of the Rocky Mountain Association of Geologists a field trip has been arranged for all day Friday, October 7. This trip will be taken along the Front Range of the Rocky Mountains, west of Denver.

The Entertainment Committee, under the chairmanship of Mr. C. J. Barker, has arranged a breakfast dance for Tuesday night, October 4, to be held in the Silver Glade of the Cosmopolitan Hotel. He also has arranged a luncheon to be held on Wednesday noon, October 5, in the Silver Glade. The luncheon will honor the Past Presidents and Charter Members of the SEG. President-elect R. C Dunlap, Jr., has agreed to be Master of Ceremonies. Special entertainment will be provided. Favors will be given, courtesy Kennecott Copper Corporation.

The Ladies Committee, under the chairmanship of Mrs. Sandy Wurth, has arranged a fashion luncheon at the Aviation Country Club for Tuesday noon, October 4. Favors will be given, courtesy Denver Area Geophysical and Supply Companies. The Ladies Committee also has arranged a mountain tour to Central City and the Park of the Red Rocks for all day Wednesday, October 5. A chuck-wagon barbecue will be served at Willow Springs.

The Finance Committee, under the chairmanship of Mr. C. E. Riddell, reports that the meeting will be more than self-sustaining. It is expected that a substantial profit will be made that will be turned over to the SEG.

The Housing Committee, under the chairmanship of Mr. Leslie Spencer, reports that as of August 23, 1955, 1,060 people have been housed, 400 of whom are women. The Denver Convention Bureau, who is handling the housing, anticipates a sharp rise in the last month prior to the meeting. A total of 1,234 rooms have been committed by the various hotels, 22 in number. The numerous excellent motels should be able to cover the hotel over-flow.

Mr. A. J. Garber, vice-chairman of the Registration Committee, Mr. W. Meszaros, chairman, reports that arrangements are nearly complete for the handling of the registration It is expected that the registration dry-run scheduled for September 8, will finalize arrangements. Plans for an Information Booth also are being made by the Registration Committee.

Mr. George Rogers, chairman of the Technical Services Committee, reports that public address equipment is available in the Lincoln Room of the Shirley-Savoy Hotel. Arrangements with a professional projectionist have been made and the special needs of the speakers have been noted. A complete list of all facilities, furniture, special equipment, and supplies used during the meetings is being prepared to guide future meeting committees. The projection equipment, public address system pointers, timer, and furniture arrangement are to be tested during the dry-run scheduled for Septem ber 8. The need for telephone communication will be determined at that time.

Mr. Henry Rase, vice-chairman of the Exhibits Committee, Mr. W. Erdahl, chairman, reports that all but three of the inside exhibit spaces and two outside exhibit spaces are rented. The Pinkerton Detective Agency is being employed to serve as guards of the booths.

Mr. James Thompson, of the Educational Exhibits Committee, reports that space has been requested by the Colorado School of Mines. This committee also will handle arrangements for student interviews.

The Publicity Committee, Mr. L. F. Lockard, Chairman, has contacted the press and radio and is making arrangements to supply copy. Biographies and pictures of speakers will be released to local newspapers about September 1. A postmark ad plate advertising the convention is being passed around to various companies using the Pitney Bowes postal meters. A press room has been arranged for during the meetings. The services of a professional press-public relations man is being considered. It was decided to have a professional photographer present at the convention.

Mr. Charles C. O'Boyle, Chairman of the General Arrangements Committee, has coordinated the activities of all committees and has accepted the responsibility for many of the program printing details.

As of September 1, all arrangements seem to be farther along than could have been hoped for. The willingness and cooperation of all those who were asked to assist has been most gratifying.

RALPH C. HOLMER, *General Vice-Chairman*
25th Annual Meeting Committee

REPORT OF THE STANDING COMMITTEE ON DISTINGUISHED LECTURES

The Standing Committee on Distinguished Lectures currently consists of:

Peter Dehlinger, Chairman
Francis F. Campbell
John Ferguson
W. B. Agocs
(one member to be appointed).

Carl H. Savit served as chairman of the Committee until Spring, 1955. (The term of the present chairman extends through the Spring of 1956.)

The fall lecturer for 1954 was Dr. C. B. Officer, then with the Woods Hole Oceanographic Institute, Woods Hole, Massachusetts, and now with Rice Institute, Houston, Texas. Dr. Officer's talk, on seismic exploration and research over oceanic areas, consisted of discussions of seismic refraction arrivals in water covered areas, recent investigations over deep oceanic areas with seismic reflection profiles, and equipment and facilities used in oceanic geophysical studies. Dr. Officer talked at the following sections:

December 6, 1954—Houston Section of SEG,
Houston, Texas.
December 8, 1954—Geophysical Society of Tulsa,
Tulsa, Oklahoma
December 10, 1954—Dallas Geophysical Society,
Dallas, Texas
December 13, 1954—Ark-La-Tex Geophysical Society,
Shreveport, Louisiana
December 15, 1954—Colorado School of Mines,
Golden, Colorado
December 16, 1954—Pacific Section of SEG,
Los Angeles, California
December 17, 1954—San Joaquin Valley Section
Bakersfield, California
January 4, 1955—Geophysical Society of Oklahoma City,
Oklahoma City, Oklahoma
January 5, 1955—Casper Geophysical Society,
Casper, Wyoming
January 7, 1955—Dakota Geophysical Society,
Bismarck, North Dakota.
January 10, 1955—Montana Geophysical Society,
Billings, Montana
January 12, 1955—Canadian Society of Exploration Geophysicists,
Calgary, Alberta.

Dr. Officer made twelve formal lectures which have been very well received. Charges for the lectures were those customarily made:

Membership of Section	Charges
50 or less	$ 1.00 per member
50–100	$ 50.00
101–200	$100.00
201–300	$125.00
300 and over	$150.00

The spring lecturer for 1955, sponsored jointly by the SEG and AAPG, was Dr. John S. Adams, of Rice Institute, Houston, Texas. Dr. Adams talked on exploration for uranium, discussing domestic and foreign exploration and production, the size and extensiveness of the uranium industry, and some

of the research carried on for new methods of exploration and extraction. Dr. Adams lectured at the following places:

April 25, 1955—Fort Worth Geophysical Society,
Ft. Worth, Texas
April 25, 1955—Dallas Geological Society and Dallas Geophysical Society,
Dallas, Texas
April 26, 1955—East Texas Geological Society
Tyler, Texas
April 26, 1955—Shreveport Geological Society and Ark-La-Tex Geophysical Society
Shreveport, Louisiana
April 27, 1955—South Texas Geological Society and South Texas Geophysical Society,
San Antonio, Texas
April 28, 1955—San Angelo Geological Society,
San Angelo, Texas
April 29, 1955—Panhandle Geological Society,
Amarillo, Texas
May 2, 1955—Oklahoma City Geological Society and Oklahoma City Geophysical Society,
Oklahoma City, Oklahoma
May 2, 1955—Tulsa Geological Society and Geophysical Society of Tulsa
Tulsa, Oklahoma
May 3, 1955—Kansas Geological Society,
Wichita, Kansas
May 4, 1955—Casper Geophysical Society and Wyoming Geological Society,
Casper, Wyoming
May 5, 1955—Montana Geophysical Society and Billings Geological Society,
Billings, Montana
May 6, 1955—Dakota Geophysical Society and North Dakota Geological Society,
Bismarck, North Dakota
May 9, 1955—Saskatchewan Geological Society,
Regina, Saskatchewan
May 9, 1955—Canadian Society of Exploration Geophysicists and Alberta Society of Petroleum Geologists,
Calgary, Alberta
May 11, 1955—Pacific Section of SEG and AAPG,
Los Angeles, California
May 12, 1955—San Joaquin Valley Section
Bakersfield, California
May 13, 1955—Denver Geophysical Society and Rocky Mountain Association of Petroleum Geologists,
Denver, Colorado

Of eighteen lectures given by Dr. Adams on this tour, the SEG sponsored thirteen jointly and one wholly. Charges for Dr. Adams' tour were considerably lower than usual SEG tours because of dual participation.

The fall lecturer for 1955 is Mr. Paul Weaver,* formerly with the Gulf Oil Corporation, Houston, Texas, and currently a Distinguished Professor of Geophysics at the Texas A. & M. College, College Station, Texas. Professor Weaver will talk on geothermal gradients and how they can be used in geophysical exploration. The tour is scheduled to start in December.

Dr. Officer has made the 15th lecture series to the SEG sections, Dr. Adams the 16th, and Professor Weaver will make the 17th.*

* Cancelled because of illness.

Considerable credit for the committee activities goes to Carl Savit, chairman of the Committee during much of the period included in this report. The committee also greatly appreciates the work of Mr. Edward W. Scott, chairman of the AAPG Distinguished Lectures Committee, in coordinating and arranging the tour of Dr. Adams.

PETER DEHLINGER, *Chairman*
Standing Committee on Distinguished Lectures

REPORT OF ACTIVITIES OF THE MEMBERSHIP COMMITTEE

March, 1954, to October, 1955

The personnel of the Membership Committee is:

T. O. Hall
F. F. Campbell
B. W. Sorge, Chairman

The continued well being of any organization depends, in part, on a stable membership. Due to conditions within the geophysical industry, there has been a larger turnover in membership during the last few years than was formerly the case. This requires that an effort be made to maintain or slightly increase the Society's membership at all times. In a technical society it is very important that this recruiting effort be made without resorting to high-pressure methods so as to avoid placing in jeopardy the professional status of the organization.

The sources of potential new members are as follows:

1. Members of local sections who are not members of the national organization.
2. Co-workers or acquaintances of members.
3. Non-members attending national or regional meetings.
4. Students.

In regard to potential members in group 1, the Membership Committee requested and obtained membership lists from all local sections. Local section members, not members of the national Society, were sent letters of invitation to join, along with application blanks. About two thousand invitations mailed in connection with this effort resulted in an increase of 141 members to June 30, 1955. It is gratifying to report that the largest percentage of these new members have become active members.

In regard to potential members in classification 2, letters and membership applications were sent to all members of the Society several months ago, with the suggestion that they interest co-workers in joining our ranks. This effort to June 30, 1955, has resulted in an addition of 162 new members.

In connection with the third source of potential members to the Society, the registration cards were obtained from the Mid-Continent regional meeting in Dallas last fall and the Gulf Coast meeting at San Antonio in the spring of this year. Letters of invitation and membership applications were sent to all registrants who were not members of the national Society. It is not possible to report on the new members obtained from among those attending the Mid-Continent regional meeting last fall. However, to June 30, 1955, among the non-members attending the Gulf Coast meeting at San Antonio last spring, four have become members of the Society.

The Membership Committee has not taken any action in regard to securing new members from the fourth group, students at recognized colleges and universities. It was the wish of the Membership Committee to make sure that our actions would not interfere with those taken by the recently re-activated Student Membership Committee. Efforts to clarify the relative sphere of activity between the two committees have not been successful at the time this report is written. It is hoped, however, that a reply from the new committee will be forthcoming to make certain that this valuable source of new members will not be neglected.

The maintenance of an active membership requires that measures be taken to avoid having members become delinquent in their membership dues. Experience has shown that a member not in good

standing is likely to drop his membership and active participation in affairs of the Society. In connection with this problem, procedures have been worked out with the business office of the Society, and the method of notifying members, who are in arrears, has been revised. Letters and reminders have been regularly sent to all those delinquent with rather gratifying results.

The figures shown below indicate the value of cooperation between the business office of the Society and the Standing Committee on Membership in this regard:

PERCENTAGE OF MEMBERS OWING DUES

	1954	*1955*
January 31	26.2%	31.2%
February 28	21.8%	12.6%
March 31	16.9%	11.2%
June 30	8.9%	4.8%

The Membership Committee suggests that the efforts to secure additional new members, as well as to maintain present members in good standing, be continued.

We would like again to state that care must be used to avoid high-pressure methods lest this activity cause injury to the high professional standing of the SEG.

Following is the report on membership growth, both for the calendar year 1954 and the six months' period January 1 to June 30, 1955:

CALENDAR YEAR 1954

	Hon. & Life	*Active*	*Assoc.*	*Student*	*Total*
Dec. 31, 1953	6	2,491	1,381	261	4,139
Elected	1	213	375	54	643
Dropped		(73)	(137)	(27)	(237)
Transferred to higher grade		(1)	(66)	(67)	(134)
Deaths		(5)	(2)		(7)
Totals	7	2,625	1,551	221	4,404

JANUARY 1 TO JUNE 30, 1955

	Hon. & Life	*Active*	*Assoc.*	*Student*	*Total*
Dec. 31, 1954 (Balance)	7	2,625	1,551	221	4,404
Elected		215	271	53	539
Dropped		(1)	(2)		(3)
Transferred to higher grade			(55)	(16)	(71)
Transferred to lower grade			(1)		(1)
Resigned		(10)	(15)	(1)	(26)
Suspended		(20)	(43)	(14)	(77)
Deaths		(1)			(1)
June 30, 1955 (Balance)	7	2,808	1,706	243	4,764

It is to be noted from the above report that the net increase in membership, which had slowed during 1954 largely due to a great number of resignations, has changed. During the first half of 1955 the net increase in membership was almost as large as that for the calendar year 1954.

During the term of office of this Committee we made the following recommendations to the Executive Committee:

A. The Membership Committee approves the present qualifications for Active Membership in Article III, Section 4, which requires "work of a responsible nature calling for independent judgment and the application of geophysical or geological principles." In particular, the committee does not favor a new membership classification intermediate between Active and Associate.

B. The Membership Committee believes that the members of the Executive Committee will have to continue to exercise judgment in the determination of the qualifications of an applicant in the future as they have in the past.

C. The Membership Committee recommends restriction of active Membership to:

1. Those doing interpretation of original data so that ordinarily only one or two men on a field party would qualify for Active Status.
2. Those engaged in field operations who for eight years have exercised complete control of techniques which affect the quality of geophysical data. (This is not intended to modify the recognition of four years of college work toward the eight year requirement.)
3. Those in laboratory positions who for at least three years have worked on research or design projects in capacities which satisfy the requirements of Article III, Section 4.

It was decided to recommend to the Executive Committee that the above definitions be included in the Procedure Manual, as well as perhaps furnished to sponsors when acting on reference blanks in connection with applications for Active Membership.

A modification of the Constitution and/or Bylaws is not considered advisable at this time.

The Membership Committee took the following actions on problems that came to its attention:

1. Modified the section on regional convention registrations of the Convention Procedure Manual.
2. Decided that it would not be advisable to develop a Society insignia, to be worn by members, unless a larger demand for this insignia exists.
3. Suggested that the business office ask applicants for membership to remit the first year's dues with their application.
4. Rejected the idea of charging applicants an initiation fee.
5. Agreed that membership certificates (for framing) should not be made available unless a larger demand for these exists.

During the last year and a half the Membership Committee has been very active. Nearly four thousand pieces of mail have been sent in connection with our efforts. It has been a privilege and a pleasure to serve the Society in this capacity.

BART W. SORGE, *Chairman*
Membership Committee

REPORT OF THE STANDING COMMITTEE ON HONORS AND AWARDS

During the year 1954–1955 the membership of the Standing Committee on Honors and Awards was:

L. L. Nettleton,	(55)
Andrew Gilmour,	(56)
George E. Wagoner,	(57)
Sigmund Hammer,	(58)
Curtis H. Johnson,	(59)

The plan of voting for a best paper award established the previous year under the Chairmanship of Norman Ricker was followed and worked out very satisfactorily. The outstanding choice among the members of the Committee was the paper on "Reflection Quality a Fourth Dimension" by Ben F. Rummerfield, published in the October number. The award was presented by Paul Lyons at the joint session of the AAPG-SEG-SEPM at the New York Meeting.

In view of the fact that the Denver Meeting is the 25th anniversary of the Society, special consideration was given to honorary membership. The Committtee has chosen three members to whom honorary memberships are to be awarded at Denver. These are Cecil H. Green, Paul Weaver and Father J. B. Macelwane.

L. L. NETTLETON, *Chairman*

REPORT OF THE STANDING COMMITTEE ON PUBLICATIONS

The members of this committee are Cecil H. Green, Sigmund Hammer, M. K. Hubbert, L. L. Nettleton, and J. P. Woods. The committee makes recommendations to the Society when questions arise concerning Society publications.

The Editor of GEOPHYSICS has received a suggestion that review papers be published. For example, a review paper might summarize all previous papers which present theoretical and experimental work on boundary waves. Review papers will be welcome. The difficulty is that a good review paper must be written by a man who is an authority in the field, and much time would be required for preparation of the paper.

The committee has considered the suggestion that the Society publish six issues of GEOPHYSICS each year instead of four. The change does not seem advisable now.

In GEOPHYSICS, v. 19, p. 855–856 (October, 1954), there is published the "SEG Policy on Publication of Technical Papers Presented at Society Meetings." The committee took part in discussions which led to these regulations.

It was decided not to add a New Products Section to GEOPHYSICS because such a section is more appropriate for a trade journal.

The committee has been asked to consider and recommend additional special publications for the Society to sponsor. A mining case histories volume has been suggested.

J. P. WOODS, *Chairman*

REPORT OF THE STANDING COMMITTEE ON REVIEWS

The Reviews Committee appointed in 1952 by the Executive Committee has completed two and one-half years of service. During this year reviews were prepared for six issues of GEOPHYSICS including July and October, 1954, January, April, July and October, 1955. The members, in addition to the Chairman, consist of W. T. Born, Thomas A. Elkins, Richard A. Geyer, E. G. Leonardon, F. A. Van Melle, Paul C. Wuenschel, and M. M. Slotnick. In addition, guest reviews were prepared by Frank Press, Brainerd Mears, Jr., G. W. Postma, A. S. Ginzbarg, L. L. Nettleton, J. T. Dewan, Arnold H. Glaser, W. M. McCardell, E. Strick and M. P. Tixier. The cooperation of guest reviewers is especially appreciated.

The number of reviews according to the subject matter is 12 on seismic subjects, 6 gravity, 7 magnetics, 3 electrical, 6 geology, 7 general, 1 mining, 3 mathematics, 1 physics, 1 geochemical, and 7 miscellaneous.

In completing his service on this Committee, the Chairman is sincerely grateful for the help given by members of the Committee. Special thanks are due to Dr. Dobrin, the Editor, for his interest in the affairs of the Committee. The Business Manager, Colin Campbell, is also to be thanked for his help in sending the many publications to the Chairman. Finally, the George Banta Publishing Company is to be commended for its accurate and attractive handling of the Reviews Section.

NELSON C. STEENLAND, *Chairman*

REPORT OF STANDING COMMITTEE ON PUBLICITY

The Standing Committee on Publicity for the period September, 1954 to September, 1955 was composed of one member from each of 18 local geophysical societies, and the Chariman:

H. C. Bickel	H. G. McCleary	T. Y. Chang	G. A. Samuels
Leonard J. Larguier	George D. Gibson	Richard S. Noble	L. W. Cobena
Julian Ashby	P. E. Narvarte	W. R. O'Brien	Leonard Zaseybida
John A. Lester	John C. McCaslin	A. A. Hunzicker	Kenneth R. Etter
Sam J. Allen			Douglas W. Allan

Some of the Committee's activities were:

1. The project begun by the Committee for the previous year was continued to further distribute copies of *Careers in Exploration Geophysics* to individuals, high school and college groups, and to various publications.

   The local Society in Calgary distributed more than 500 copies of the brochure to every high school of any size in English-speaking Canada.

   The Denver Geophysical Society's Committeeman and his assistants distributed 700 copies with accompanying explanatory letters to 7 high schools in Denver and suburbs and to 13 universities, colleges, and junior colleges in Colorado.

   Members of the Casper, Wyoming, Geophysical Society spoke before high school classes in at least 15 Wyoming towns in their distribution of this booklet.

   The South Texas Geophysical Society, under the leadership of its Committeeman, supplied speakers at eight high schools or colleges, where student attendance at the meetings ranged from 25 to 100. The visiting geophysicists spoke for approximately 20 minutes concerning opportunities in geophysics, showed a 20-minute colored sound film, and after a question-and-answer period offered copies of *Careers in Exploration Geophysics*. More than 500 copies were distributed in this manner.

   Other members of the Standing Committee on Publicity were similarly engaged in this project.
2. An outline of the Committee's functions was prepared to be placed in the *Procedure Manual*.
3. Publicity releases were sent to a mailing list of some 150 newspapers and magazines or bulletins. These releases were forwarded to those outlets with a view to location, general or specific interest, and timeliness of the event or individual sought to be publicized.
4. Publicity was given the *Report on Geophysical Activity in 1954*, the *SEG Safety Award for 1954*, and *Honorary Membership Awards for 1955*.
5. Publicity and distribution of copies of the article *Exploration Geophysics* in the January, 1955 issue of Air Trails HOBBIES FOR YOUNG MEN were undertaken.
6. Local, regional, and national meetings and other activities of the SEG were given publicity by news releases, posters, and through other media. Particular attention was given to publicizing the 25th Anniversary Meeting of the SEG held in Denver by issuing special seals, placards, and a postmark for use on correspondence.
7. Special publicity releases were mailed to news outlets concerning individual members of the SEG in an effort to obtain as wide coverage as possible.
8. Members of the Committee addressed their local and other Societies, high schools and colleges or universities, and civic groups concerning matters pertaining to the SEG.
9. The Committee secured papers given at local, regional, and national conventions for publication in the *Oil & Gas Journal*, *World Petroleum*, *Oil in Canada*, GEOPHYSICS, and other periodicals.

The Committee wishes to express to Colin C. Campbell, Business Manager, SEG, its appreciation for his assistance and unfailing cooperation in all matters pertaining to performance of its duties.

BEN F. RUMMERFIELD, *Chairman*

REPORT OF THE STANDING COMMITTEE ON PUBLIC RELATIONS

The Standing Committee on Public Relations has completed its major project. For the past two years the committee has been engaged in the preparation, publication, and distribution of "Careers in Exploration Geophysics."

In the late summer of 1954 the Society published 100,000 copies of the booklet. Of these, approximately 25,000 were sold to the exploration industry for private distribution and a similar number were mailed by the Society to the high schools in the United States and Canada. During the fall of 1955 a second mail distribution of 25,000 copies is being made by the Society to high schools. This will leave an inventory of 25,000 booklets for sale to industry or other distribution.

"Careers in Exploration Geophysics" is a long range project, and therefore some years will pass before an accurate evaluation can be made. However, the initial response has been gratifying as evidenced by approximately 550 inquires from students, parents, guidance directors, and other individuals. The Business Office has handled a majority of this correspondence but numerous letters have been forwarded to the Chairman for reply.

Prior to publication in 1954 the Society budgeted $2,500.00 for the above project. We are pleased to report initial sales to industry have been greater than expected with the result that approximately $1,980.00 of the Society's funds have been used. It is anticipated future orders will make up most, if not all, of this amount.

R. C. DUNLAP, JR., *Chairman*

ANNUAL REPORT OF SPECIAL GLOSSARY COMMITTEE

(AGI GLOSSARY SUB-COMMITTEE)

The compilation phase of the Geophysics portion of the AGI Glossary has been completed. However, it is the opinion of the AGI editorial staff that, in order to preserve a continuity of style, every AGI sub-committee should select one person to review its particular glossary.

Paul L. Lyons has kindly agreed to take on this rather formidable job, involving about 1,000 words. He reports that this phase of the work will be completed in time for the AGI's deadline for the completion of the entire glossary.

As chairman of the SEG Committee, I would like to take this opportunity to express my appreciation for the excellent cooperation of the members of the committee on this project, as well as to Paul Lyons and numerous other members of the SEG, without whose help this glossary could never have been completed in the time allowed.

RICHARD A. GEYER, *Chairman*

REPORT OF THE SEG SAFETY COMMITTEE

The Committee's activities closely paralleled the patterns set in previous years as to the continuation of current projects and the initiation of new ones.

1. Sponsorship and continuous promotion of the Accident Information Exchange as a valuable source of accident causes and types within the industry. Relatively few geophysical operators are regular contributors to this project and a more effective campaign should be waged to enlist the cooperation of more companies.
2. Collection and compilation of accident statistics monthly. A statistics card and a letter soliciting statistical information is mailed to every geophysical contracting company, to all oil company geophysical departments and to shot hole drillers. Some fifty or sixty of these cards are returned each month and the information thus compiled forms a valuable accident experience record of the industry.
3. The Committee edits and publishes a bi-monthly safety organ, *Geophysical Safety Tips*. This publication is designed as a source of safety meeting materials for use by the Party Chiefs.
4. The Committee sponsors the publication of a quarterly safety booklet entitled, *Doodlebuggin' The Safe Way*. This booklet is sold to companies who pass it out to all employees. The purpose of this booklet is the creation of safety-mindedness.
5. The Committee developed a booklet for the purpose of assisting in the safety indoctrination of new employees. This booklet has been well received and is now in its second printing.
6. The sale of Safety Posters has fallen to a low number probably due to the lack of new and fresh poster material and ideas. This project should be revived possibly along the lines of issuing a small kit of posters each month on a yearly subscription basis.
7. A subcommittee has been active on the development of a source or sources of finances for the making of a special safety film on explosives hazards. Prospects for financing this project on an adequate basis seem very discouraging at this time.

8. The Committee has cooperated with a commercial producer of slides in the production of several sets of safety slides that are now available for purchase.
9. Committee meetings were held in Dallas in November 1954, and in San Antonio in May 1955, on the occasions of regional Meetings of the Society.
10. A new project begun during the fiscal year is the development of a special safety graph or flip chart as a visual aid especially adapted to the industry. This project has developed slowly through the final art work stage but has had to be temporarily suspended. It is anticipated that this project will be carried to completion soon after the appointment of the new Committee Chairman.

JOHN F. IMLE, *Chairman*

GEOPHYSICAL CASE HISTORIES COMMITTEE—VOLUME II

I have the following to report on the status of *Geophysical Case Histories*, Volume II.

Two years ago next month my committee received its instructions to plan and complete "Volume II." There are to be 52 papers in the new volume and though the printer promises it by October 1955, Paul Lyons advises me it will more likely be November 1955 before it is finally printed and ready for sale.

Since most of the papers were sent to Paul Lyons, I cannot pass judgment on them but he is satisfied that the volume will be an excellent contribution to geophysical literature.

I wish to express thanks and appreciation for the cooperation and interest on the part of the many individuals who prepared the papers and the organizations which so generously released the data for the book. The help and advice of the SEG Executive Committee as well as the counsel of those who worked on the first volume was greatly appreciated.

D. P. CARLTON, *Chairman*

SUBCOMMITTEE ON MINING GEOPHYSICAL CASE HISTORIES

The efforts of the Subcommittee during the past year have been directed towards the formulation of policy regarding the proposed Case Histories Volume and to the solicitation of papers which might be suitable for the volume. One new committee member has been added in the person of J. R. Balsley of the USGS.

On being informed of the aims of the subcommittee, the European Association of Exploration Geophysicsts, at their Paris meeting in May 1955, set up a committee of four, with E. H. Hedstrom as Chairman, to assist in the project. The EAEG has also suggested that they would be willing to supply part of the financial support necessary for a Case History Volume providing that it be issued as a joint publication. This suggestion is now under consideration.

An estimate has been made of the potential market for a volume of Mining and Engineering Geophysics Case Histories. The Publications Committee will now attempt to estimate the probable number of copies to be sold in order to determine the financial feasibility of publishing the volume.

HAROLD O. SEIGEL, *Chairman*

REPORT OF THE CONSTITUTION AND BYLAWS COMMITTEE

This is a report of the Constitution and Bylaws Committee of the Society of Exploration Geophysicists. Since the last annual meeting, the Committee has considered the constitution and bylaws of the following societies which desired to affiliate with the Society of Exploration Geophysicists.

University of Utah Geophysical Society
Student Geophysical Society of Texas Western College
Pennsylvania State University Geophysical Society

In addition to this, the Committee has considered the question of revising the Bylaws to permit inactive status for foreign members who have difficulty in paying dues because of currency regulations.

The Committee felt that this was a very rare problem and one which is fairly met by the existing provisions of the Constitution and Bylaws and, therefore, recommended no change.

The Committee also considered the question of increasing dues of each grade of membership 50¢ per annum. It was the opinion of the Committee that this was an action which should be recommended by the Executive Committee rather than by this Committee because of their familiarity with the financial status of the Society.

A major activity has been the consideration of a number of modifications of the Constitution and Bylaws suggested by Mr. Milton Dobrin as a result of the changes in the activities and procedures since the last major revision of the Constitution and Bylaws. Because of the large number of problems involved, action on these suggestions has been postponed to a meeting of the Constitution and Bylaws Committee to be held at Denver during the annual meeting in October, 1955.

W. M. RUST, JR., *Chairman*

REPORT OF THE COMMITTEE ON STANDARDIZATION OF MAGNETIC RECORDING

Since the first meeting of this Committee held in Tulsa, Oklahoma, June 28, 1954, two additional meetings have been held, one in Dallas November 18, 1954, and one in New York March 31, 1955. Two Subcommitttees have been appointed to study specific aspects of the standardization problem. One Subcommittee on Definitions and Measurement Procedures with Mr. W. E. N. Doty as Chairman is working on standardizing the definitions of terms used in specifying recorder characteristics and the procedures used in measuring recorder performance. A second Subcommittee on Information on Recorder Characteristics under Mr. C. B. Scott has undertaken the task of compiling information on the characteristics of all commercial recorders, so that it will be readily available to the industry, and suggesting features which might be standardized.

It was the opinion of the Committee from the beginning that it is neither feasible nor desirable at the present time to standardize recorders to the extent that records made on one type of recorder can be played back on another. This is because many of the features involved in such standardization are important in determining the quality of the recordings and the uses to which they may be put. Developments have not yet progressed to the stage that specific recommendations can be made for providing complete standardization. For example, certain recorders may use fixed magnetic heads mounted in a single block while others may require individually mounted heads which may or may not be movable along the recording track, depending upon the uses which are to be made of the records. The spacing needed for the different types of heads may be different so that a standardized head spacing is not feasible. It might be that head spacing could be narrowed down to a few preferred values, however, as soon as sufficient performance information is available.

Another important dimension of recorders is the total recording time provided. If this were the same for all recorders, the problem of making transcriptions from one type of record to another would be substantially simplified. The Subcommittee on Information on Recorder Characteristics is working on these and similar problems and it is expected that specific recommendations will be made as rapidly as can prudently be done.

The Subcommittee on Definitions and Measurement Procedures has undertaken the task of making uniform the terms used to specify recorder characteristics and performance. This task is complicated by the several types of systems being used or developed (frequency modulation, direct recording, pulse width modulation) and by the fact that some of the important quantities, such as noise, are difficult to specify. Some aspects of noise are important for certain purposes and other aspects are important for others. The Subcommittee is undertaking to work out simple definitions and methods of measurement which will be uniformly applicable and will give the important information on all recorders. This will insure the users of magnetic recorders that they understand the performance of the recorders and the relative merits of the various types.

Developments in magnetic recording have progressed very rapidly in the past year and many

new ideas have emerged, particularly with regard to the use of such recording. The Committee feels that freedom to experiment and to make improvements should be maintained without any hampering effects from premature standardization. It is of vital importance that this new field be explored fully in order that the greatest value from new methods based on this new type of recording can ultimately be realized.

It is believed that the two Subcommittees which have been set up are performing a very useful function and will be effective in aiding in standardization as rapidly as can reasonably be expected. Reports from the two Subcommittees follow.

R. R. THOMPSON, *Chairman*

REPORT OF THE SUBCOMMITTEE ON DEFINITIONS AND MEASUREMENT PROCEDURES

The SEG Subcommittee on Definitions and Measurement Procedures has been set up by the SEG Committee on Standardization of Magnetic Recording of Seismic Signals. The Subcommittee assignment consists of preparing suggestions for definitions and measurement procedures to be used to specify performance characteristics of magnetic recording equipment as applied to geophysical uses. The Subcommittee met October 12, 1954, in Fort Worth and again August 11 and 12, 1955, in Houston, Texas. Problem teams working on particular phases of the problem have met on numerous occasions.

In considering the assignment, the Subcommittee recognizes that it is not to attempt to set up standards of performance, but only to suggest definitions and measurement procedures which, if adopted, will establish greater uniformity in the manner performance characteristics are specified. A second objective of the Subcommittee is to suggest measurement and reporting procedures which will provide adequate data in such form as to facilitate an accurate evaluation of a magnetic equipment for a particular application.

It is the opinion of some members of the Subcommittee that suggestions pertaining to terminology and measurement procedures should be given the standing of proposed standards only after very careful study. This takes time. The Committee recognizes the immediate need of some measures to eliminate the misunderstanding regarding the measurement and reporting of particular performance characteristics.

Suggested procedures will be submitted in the near future which will require sufficient data to assure accurate appraisal of performance. These suggestions can constitute the basis for standards after experience has proved them to be useful and sound.

It is thought that this course of action will best accomplish the immediate and long-range objectives set out by the parent Committee.

W. E. N. DOTY, *Chairman*

REPORT OF THE SUBCOMMITTEE ON INFORMATION ON MAGNETIC RECORDER CHARACTERISTICS

A Subcommittee on Information on Magnetic Recorder Characteristics has been formed. This Committee is composed of Mr. C. B. Scott, Dr. Sidney Kaufman and Dr. A. L. Parrack. The objective of this Subcommittee will be to supply and publish information on the dimensions and characteristics of the various types of magnetic recorders being manufactured. The Committee has made a preliminary listing of the known characteristics of the various types of magnetic tape equipment that is available. The Committee invites all manufacturers to cooperate in helping it to maintain up-to-date and accurate information on the characteristics of their equipment.

The various systems will be grouped according to FM, pulse modulated and AM types. For each group it is planned to list clear information on recording time, linear speed of travel of recording medium, tape width, head positioning, head spacing, whether or not the heads are movable, individual track width and spacing, input and output voltage and impedance levels, number of channels, ap-

proximate power consumption and approximate size and weights. The Subcommittee will steer clear of controversial characteristics, such as signal-to-noise ratio, until such time as the main Committee can resolve these controversies through its Subcommittee on Definitions and Measurement Procedures.

The Subcommittee will strive to report only that information which it knows to be entirely correct and to represent average performance. It will make or arrange for, where necessary, measurements or determinations to assure that any data are correct before publication.

In the process of supplying information which it hopes will be useful to members of the SEG, the Subcommittee will point out particular items which would be of importance to the users if some measure of standardization could be obtained.

C. B. Scott, *Chairman*

REPORT OF SEG RESEARCH COMMITTEE

The SEG Research Committee was organized in the fall of 1954 to consider ways by which the Society of Exploration Geophysicists could encourage research in geophysics that would be of interest to the membership.

The establishment of this committee recognizes the maturity which the technology of exploration geophysics is now attaining. In its early days, exploration geophysics borrowed heavily from developments in the communications industry as well as from classical geophysics. Now, however, it is becoming increasingly evident that there are special areas in the science of geophysics that are of particular interest to exploration geophysicists and are in need of fundamental investigation. These special areas are outside the areas of chief interest of other groups and are therefore primarily the responsibility of the exploration geophysicists.

The first meeting of the newly formed Research Committee was held in New York last spring during the annual meeting of the SEG. The membership of the committee is made up of representatives from universities, geophysical service companies, and petroleum companies.

It was agreed by all members of the Research Committee that geophysical research in colleges and universities should be encouraged in every practical way. The Committee agreed that any research selected for support by the SEG should be of a fundamental nature, having as its objective an increase in our understanding of geophysical phenomena; it should avoid having short range objectives that might be of immediate competitive significance. It was also agreed that a rather broad interpretation of geophysics should be assumed; the application of nuclear physics to age measurement of rocks should be included, in addition to the usual fields of terrestrial magnetism, gravity, seismology, electrical earth currents, and geothermal gradients.

The committee voted to take the following five specific actions:

1. Recommend to the American Petroleum Institute, which has funds available for the support of fundamental research, that research in geophysics be supported in one or more of the following three fields listed in their order of preference:
   a. Seismic wave propagation through sedimentary materials including absorption and/or scattering.
   b. Geophysical studies on the static and dynamic problems concerned with basin formation.
   c. Thermal conductivity measurements in the earth's crust along the lines of Birch's recent review article in Geophysics.
2. Prepare a list of geophysical problems which could be suggested as subjects for thesis work by graduate students in universities. It is realized that most universities already have a good backlog of thesis problems, but a special objective of the proposed list would be the selection of problems that could be based on data that could be made available from commercial geophysical operations. Such lists could be sent to institutions engaged in geophysical research and could also be published in Geophysics in order to help solicit needed data.
3. Give consideration to the sponsoring of symposia at various universities for the purpose of bringing university and petroleum research workers together in fields of common interest.

4. Recommend to the Editor of the SEG that an annual review paper be published in GEOPHYSICS which would underline significant research developments during the past year.
5. Recommend to the Executive Committee of the SEG that the latter offer its assistance and cooperation to the National Science Foundation in the activities of the International Geophysical Year (1957–1958).

Progress is being made on all five of the above items. The American Petroleum Institute has already given general approval to the support of geophysical research and has appointed a special committee to review geophysical work now in progress in this country. It is probable that funds for the support of specific projects in geophysical research will be budgeted at the November meeting of the API in San Francisco.

A subcommittee to suggest the list of special geophysical problems for thesis work has been appointed under the chairmanship of L. L. Nettleton. The membership of the subcommittee is:

L. L. Nettleton—Gravity Meter Exploration Company
Cecil H. Green—Geophysical Service, Incorporated
B. D. Lee—The Texas Company

The subcommittee on considering the feasibility of sponsoring symposia at universities for the purpose of bringing academic and industrial research workers together has R. A. Peterson as chairman. The membership of this subcommittee is:

R. A. Peterson—United Geophysical Corporation
C. H. Dix—California Institute of Technology
N. Allen Riley—California Research Corporation

Milton Dobrin, Editor of GEOPHYSICS, and Robert G. Van Nostrand have been commissioned by the Research Committee to prepare a paper reviewing new developments in geophysics during the past year. This paper will be presented at the Denver meeting of the SEG by Milton Dobrin. It will also be presented at the London meeting of European Association of Exploration Geophysicists in December by Dr. Van Nostrand, who will be the official representative of the SEG at this meeting.

President Lyons has written a letter to the National Science Foundation offering the assistance and cooperation of the SEG in the activities of the International Geophysical Year (1957–1958).

The Committee is thus pleased to report that action has been taken on all five of the recommendations made at the New York meeting.

D. H. CLEWELL, *Chairman*

REPORT OF THE SPECIAL COMMITTEE ON THE INDEX OF WELLS SHOT FOR VELOCITY

The Index of Wells Shot for Velocity Committee is pleased to report that the first supplement to the "Index of Wells Shot for Velocity," published in booklet form in 1953, is nearing completion. Our present plans are to have the supplement ready for publication in the January 1956 issue of GEOPHYSICS.

We feel that sufficient time has elapsed since the 1953 "Index" was published to warrant the publication of this supplement. The response to our letter mailed early in 1955, soliciting new survey listings, has been very good. We wish to thank the oil companies, cooperative well velocity survey associations, seismograph contracting companies and individuals for supplying the committee with the requested velocity information. Without the full cooperation of the various companies, associations and individuals, the preparation of such an index would not be possible.

This supplement will show surveys not heretofore reported in any of the previous publications, most of which will be surveys shot since July 1952. Corrections and additional information on previously listed surveys will also be included.

V. U. GAITHER, *Chairman*

REPORT OF ADVISORY COMMITTEE ON RADIOACTIVE MINERAL EXPLORATION

The Committee continues to meet twice each year. The last meeting was held in Houston May 17.

Messrs. Green, Higgs, Johnson and Lahee were re-elected for three-year terms.

Dr. F. H. Lahee was re-elected Chairman and Mr. Cecil H. Green, Vice Chairman.

Reports to the Committee show that more oil and gas companies and individuals are directly or indirectly exploring for radioactive minerals in the United States and Canada than at any time in the past.

Six Informational Circulars have been distributed to date.

The fall meeting will be held in Dallas on Friday, October 28.

HENRY C. CORTES, *Past Vice Chairman*

SPECIAL BUSINESS OFFICE COMMITTEE REPORT

This committee was appointed on November 11, 1954, because the Executive Committee felt that the Society, and especially the Business Manager and the Secretary-Treasurer, would be materially benefited by the permanent continuation of a business office committee. Previously a special committee under the chairmanship of Mr. Karl Dyk had taken care of several of the most pressing situations (see GEOPHYSICS, Vol. XIX, p. 618, July, 1954). Shortly after our committee began functioning, several visits to the business office and discussions with the Business Manager resulted in improvements of handling delinquent accounts. The matter of extending credit to individuals was revised and improved. Suggestions were made to set out more clearly certain items in the bookkeeping procedure. The monthly balance sheets which Mr. Colin Campbell furnishes the committee (at the suggestion of Mr. Thralls, the Secretary-Treasurer) reflect that these suggestions were favorably received. We believe that the accounts are clearer and more understandable.

A few days prior to the New York convention we submitted an interim report to President Paul Lyons, in which several of these suggestions were discussed. Our main recommendation in the aforesaid report deals with a list of index of velocity surveys. Although this matter concerns mainly the committee on velocity index, it was felt that the matter is sufficiently important from the standpoint of additional revenues to the Society that the Business Office Committee should bring it up again. We believe it advisable to repeat and emphasize the reasons why a velocity index is extremely desirable and to elaborate further on the four points given in our interim report.

1. The cost of preparing a cumulative index for well velocities similar to the way our membership list is prepared is not at all prohibitive. Mr. Campbell assured us that preparing the report would be relatively easy, since business machinery is set up for similar purposes, and the main requirement would be continuous reporting of velocities shot.

2. When the last index was published, a great many complimentary copies were given away without cost to the recipient. We felt then and still feel that this is an unnecessary generosity. An index is a necessity to most oil companies, and from numerous inquiries it is quite obvious that the various geophysical departments of companies would gladly pay many times the cost of the original index provided it is kept up to date and the information is received regularly by the companies.

3. Discussions with Mr. Campbell and Mr. Thralls indicated that a very close estimate can be made of the number of copies likely to be sold; therefore the printing of a substantial excess can be eliminated. We lost money on the original index because too many copies were left over. It has been assumed that a good many individuals would buy the index, which was not the case. Also, $2.50 was too cheap.

4. In our interim report we suggested the price of $10 per copy. Since that time we have revised this suggestion and would like to raise the price. We feel that $20 to $25 would not be out of line.

In view of the above, we suggest that the velocity index committee be instructed to discuss the details with Mr. Colin Campbell, who is quite familiar with our suggestions. It would be extremely desirable to have a usable index as soon as possible.

Apparently it is contemplated to print the reports of all SEG committees and distribute them to members attending the convention in Denver. We all know that the majority of the membership will not read these reports even though some may pick up the printed matter. After carrying it around during the convention, many will throw it away. We suggest that only the officers of the Society and members of the various committees receive copies and that in addition only a limited number be printed for those really interested. We feel we could save some money by this procedure.

Recently the contemplated move of the SEG headquarters from the Elm Oil Building to the AAPG Building was analyzed, and our committee voted in favor of the move.

Also recently we suggested to the Executive Committee that additional help be hired for the business office staff and that certain salary adjustments be made. We believe that the Society can afford these adjustments, and that they will tend to improve the efficiency of the business office. We recommend, therefore, that a bookkeeper be hired, and that salary adjustments as set forth in the letter and schedule of August 19 to President Paul Lyons be granted at an early date.

From the auditor's report recently completed, it is evident that the Society closed the fiscal year with a substantial surplus. This is a good situation, and we feel that by further streamlining of the business activities, the affairs of the SEG can be kept out of the red; and if activities continue to grow as they have during the past year, the well-being of the Society seems assured.

We want to comment on the splendid cooperation that Mr. Colin Campbell has given the committee. Not only has he furnished regularly the monthly balance sheets, the *Doodlings* of the SEG, the business office activity reports, personnel data, and job evaluation; but also he has received with enthusiasm the various suggestions offered by our committee. The committee wants to thank everybody who has assisted us in our work. It is our opinion that the Society had a good year.

STEFAN VON CROY, *Chairman*

ANNOUNCEMENTS

THE INTERNATIONAL GEOPHYSICAL YEAR

Fourteen special committees and technical panels have been appointed by the U. S. National Committee for the International Geophysical Year (USNC-IGY). The USNC-IGY was established by the National Academy of Sciences to plan, direct, and execute the U. S. Program during the International Geophysical Year 1957–1958. Federal sponsorship and funds have been obtained by the Academy's Committee through the National Science Foundation, the government agency responsible for federally supported basic research. To date the Congress has appropriated $12 million for the program.

During the IGY the scientists of forty nations will conduct the most comprehensive study of the earth ever undertaken. Intensive investigations throughout the world will be carried out in meteorology, latitude and longitude determinations, geomagnetism, gravity measurements, ionospheric physics, aurora and airglow, solar activity, cosmic rays, glaciology, oceanography, seismology, rocket exploration of the upper atmosphere, and the earth satellite program.

Technical panels, composed of experts in the various IGY disciplines, have been formed by the USNC-IGY for detailed planning purposes. Membership in the USNC-IGY and its subcommittees and panels is as follows:

USNC-IGY Committees and Panels

1. *U. S. National Committee*

Joseph Kaplan, *Chairman*
A. H. Shapley, *Vice-Chairman*
N. C. Gerson, *Recording Secretary*
Hugh Odishaw, *Executive Secretary*

L. H. Adams
Allen v. Astin
H. G. Booker
Lyman J. Briggs
G. M. Clemence
Earl G. Droessler
C. T. Elvey
John A. Fleming
Laurence M. Gould
E. R. Piore
F. W. Reichelderfer
E. B. Roberts
A. Nelson Sayre
Paul A. Siple
A. F. Spilhaus
Merle A. Tuve
A. L. Washburn

Ex-Officio Members:
Wallace W. Atwood, Jr.
Lloyd V. Berkner
J. Wallace Joyce
Walter M. Rudolph
H. K. Stephenson

2. *USNC Antarctic Committee*

Richard E. Byrd, *Honorary Chairman*
L. M. Gould, *Chairman*
Hugh Odishaw, *Secretary*
John Hanessian, *Recording Secretary*

Bernt Balchen
Richard B. Black
George Dufek
N. C. Gerson
Grant G. Hilliker
A. H. Shapley
Paul A. Siple
A. L. Washburn

Consultants:
J. Glenn Dyer
William O. Field
Finn Ronne
Harry Wexler

3. *USNC Data Processing Committee*

W. A. Wildhack, *Chairman*
G. F. Schilling, *Recording Secretary*

John C. Bellamy
F. N. Frenkiel
H. E. Landsberg
Ralph J. Slutz

Consultants:
Julius F. Bosen
H. K. Skramstad
Joshua Stern

4. *USNC Technical Panel on Aurora and Airglow*

JOSEPH KAPLAN, *Chairman*
SYDNEY CHAPMAN, *Ex-officio*

C. T. Elvey
C. W. Gartlein
A. B. Meinel
D. H. Menzel
Norman J. Oliver
A. M. Peterson
F. E. Roach
Richard Tousey
E. H. Vestine

Consultants:
D. K. Berkey
G. Gordon Little

5. *USNC Technical Panel on Cosmic Rays*

S. E. FORBUSH, *Chairman*
SERGE A. KORFF, *Executive Secretary*

H. V. Neher
E. P. Ney
J. A. Simpson
S. F. Singer
J. A. VanAllen

Consultants:
R. J. Mackin
W. S. Otting
M. M. Shapiro
D. L. Worf

6. *USNC Technical Panel on Geomagnetism*

E. O. HULBURT, *Chairman*
E. B. ROBERTS, *Secretary*

Leroy R. Alldredge
Walter Elsasser
R. R. Revelle
Merle A. Tuve
Victor Vacquier
E. H. Vestine

Consultants:
A. G. McNish
J. H. Nelson

7. *USNC Technical Panel on Glaciology*

WILLIAM O. FIELD, *Chairman*
FRANK PRESS, *Vice-Chairman*
J. HANESSIAN, *Secretary*

George Rigsby
Robert P. Sharp
Paul A. Siple
A. L. Washburn

Consultants:
R. F. Flint
R. P. Goldthwait
D. Linehan

8. *USNC Technical Panel on Ionosphere*

MILLETT G. MORGAN, *Chairman*
H. W. WELLS, *Secretary*
R. C. PEAVEY, *Recording Secretary*

H. G. Booker
Frederic Dickson
R. A. Helliwell
Wolfgang Pfister
A. H. Shapley
Ralph J. Slutz
A. H. Waynick

Consultants:
H. W. Curtis
H. E. Dinger
A. G. Jean
A. M. Peterson

9. *USNC Technical Panel on Longitude and Latitude*

WILLIAM MARKOWITZ, *Chairman*
WILLIAM M. SMITH, *Recording Secretary*

Carl I. Aslakson
G. M. Clemence
Donald A. Rice

10. *USNC Technical Panel on Meteorology*

B. HAURWITZ, *Chairman*
D. F. LEIPPER, *Executive Vice-Chairman*
R. N. CULNAN, *Recording Secretary*

C. R. Dale
Robert D. Fletcher
Sverre Petterssen
Harry Wexler
Robert M. White

Consultants:
J. H. Hughes
J. A. Mirabito

11. *USNC Technical Panel on Oceanography*

GORDON LILL, *Chairman*
STANLEY RUTTENBERG, *Recording Secretary*

Maurice Ewing
R. H. Fleming
Columbus O'D. Iselin
D. F. Leipper
Roger R. Revelle
E. H. Smith

Consultants:
H. H. Carter
W. D. Claus
J. R. Cloyd
B. K. Couper
L. P. Disney
John Lyman
R. C. Vetter
L. A. Walford

12. *USNC Technical Panel on Rocketry*

F. L. WHIPPLE, *Chairman*
H. E. NEWELL, JR., *Executive Vice-Chairman*
G. F. SCHILLING, *Secretary*

W. Berning
W. G. Dow
N. C. Gerson
B. Haurwitz
J. Kaplan
W. J. O'Sullivan
S. F. Singer
W. Stroud
J. A. Van Allen
P. Wyckoff

Consultants:
N. W. Spencer
L. M. Jones
F. B. McDonald
R. M. Slavin
J. W. Townsend

13. *USNC Technical Panel on Seismology and Gravity*

JAMES B. MACELWANE, *Chairman*
MAURICE EWING, *Vice-Chairman*
H. E. TATEL, *Secretary*
J. HANESSIAN, *Recording Secretary*

Roland F. Beers
Hugo Benioff
Dean S. Carder
A. P. Crary
William O. Field
Donald A. Rice
Merle A. Tuve
George P. Woollard

14. *USNC Technical Panel on Solar Activity*

A. H. SHAPLEY, *Chairman*
WILLIAM M. SMITH, *Recording Secretary*

Horace Babcock
John W. Evans
Leo Goldberg
John P. Hagen
S. B. Nicholson
W. O. Roberts

15. *USNC Technical Panel on World Days and Communications*

A. H. SHAPLEY, *Chairman*

John W. Evans
A. B. Meinel
Millett G. Morgan
Homer E. Newell, Jr.

Consultants:
A. M. Peterson
R. J. Slutz
R. C. Vetter

For further information, address the Executive Secretary, U. S. National Committee for the IGY, National Academy of Sciences, 2101 Constitution Avenue, Washington 25, D. C.

CALENDAR OF MEETINGS

1956

February

1	Acoustical Society of America, New York
1	Optical Society of America, New York
9–11	Institute of Radio Engineers, Eighth Annual Southwestern Conference and Electronics Show, Municipal Auditorium, Oklahoma City, Oklahoma
19–23	American Institute of Mining and Metallurgical Engineers, Annual meeting, Hotel Statler, New York (Contact E. O. Kirkendall, AIME, 29 W. 39th St., New York 18, New York)
24–25	American Physical Society, Houston, Texas (Contact C. W. Heaps, The Rice Institute, Houston, Texas)

March

8– 9	Society of Exploration Geophysicists, Regional meeting, Ft. Worth, Texas
19–22	Institute of Radio Engineers, and Radio Engineering Show, National Convention, Waldorf-Astoria Hotel and Kingsbridge Armory and Palace, New York, New York

April

5– 7	Optical Society of America, Philadelphia, Pennsylvania
23–26	American Association of Petroleum Geologists, 41st Annual meeting, Chicago, Illinois
25–29	World-Oil Exposition, Houston, Texas
26–28	American Physical Society, Washington, D. C.
30– 2	American Geophysical Union, Annual meeting, Washington, D. C.

May

11	Society of Exploration Geophysicists, Annual Spring meeting, Pacific Coast Section, El Tejon Hotel, Bakersfield, California
12	Permian Basin Geophysical Society, Annual meeting, Scharbauer Hotel, Midland, Texas
17–18	Society of Exploration Geophysicists, Gulf Coast regional meeting, Houston, Texas

October

28– 1	Society of Exploration Geophysicists, 26th Annual meeting, Roosevelt Hotel, New Orleans, Louisiana

November

12–15	American Petroleum Institute, 36th Annual meeting, Conrad Hilton Hotel, Chicago, Illinois

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10–15	Society of Exploration Geophysicists, 27th Annual meeting, Statler-Hilton Hotel, Dallas, Texas

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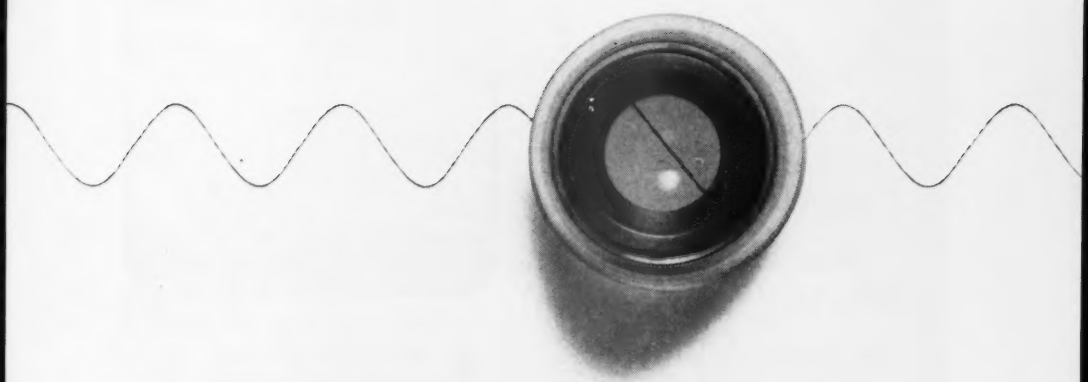

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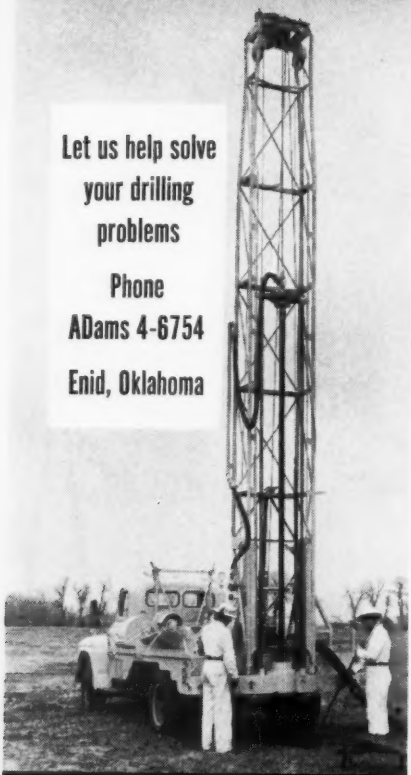

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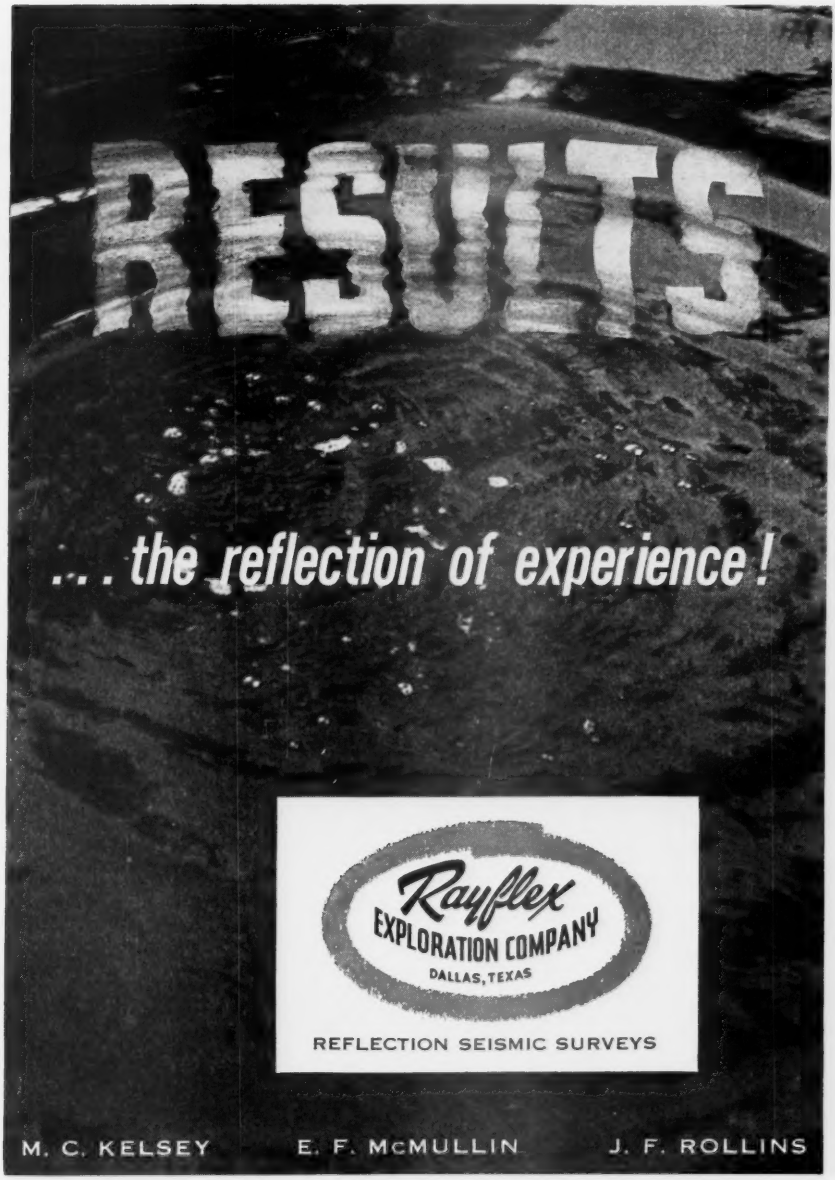
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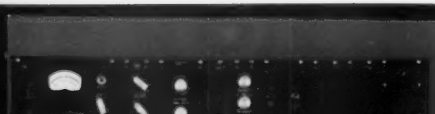

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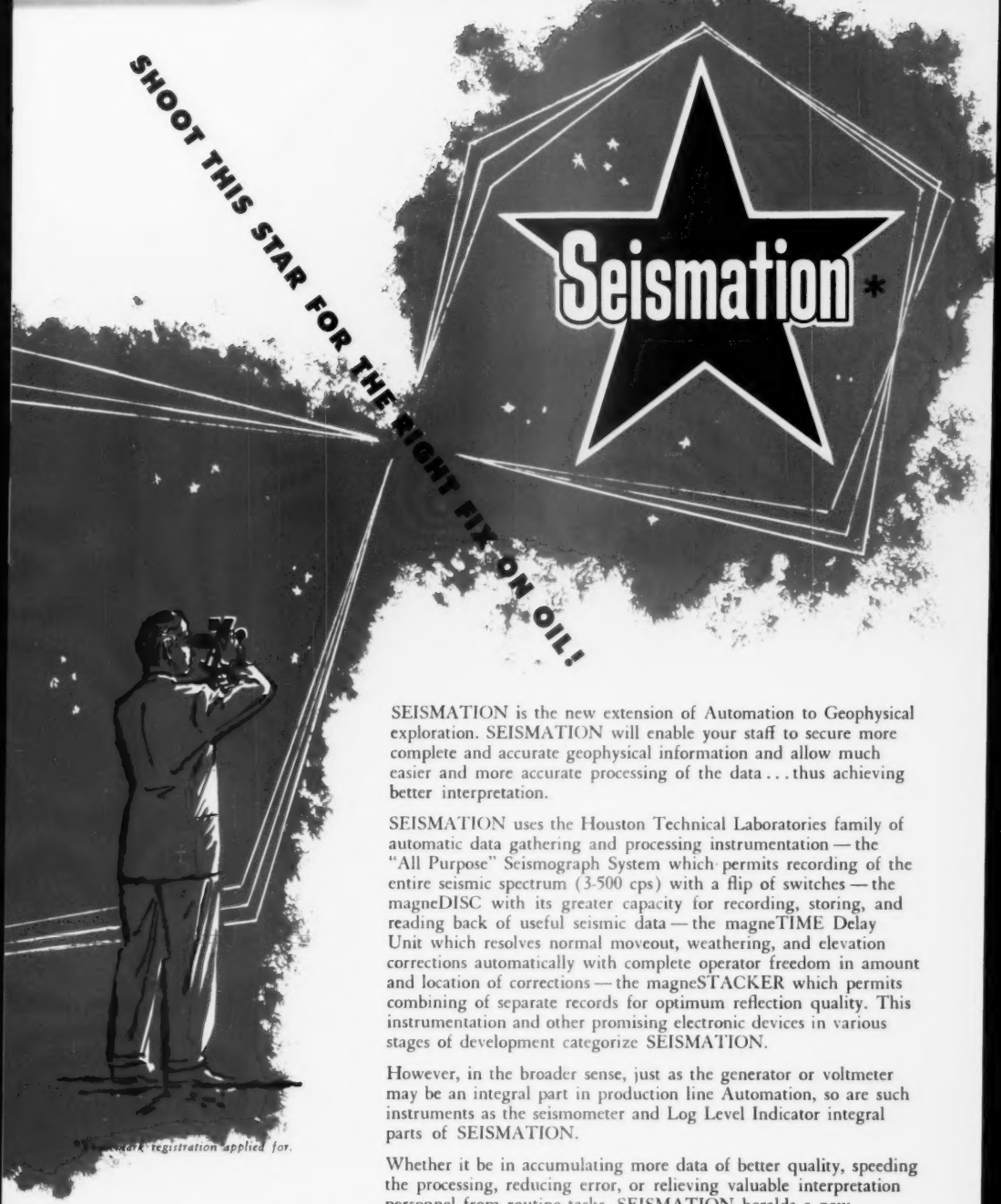

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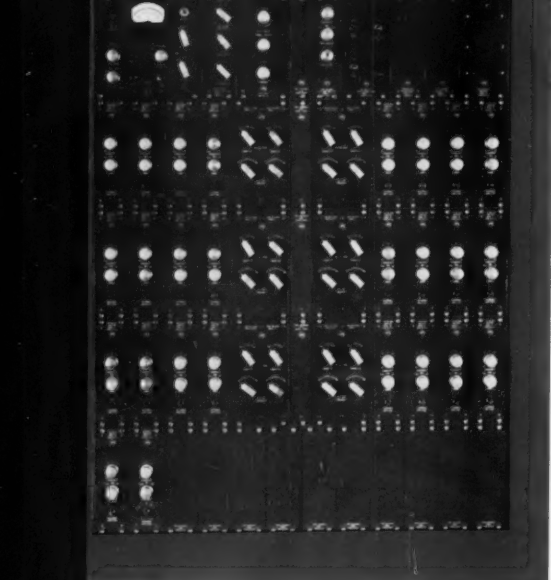

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Height	1⅞ inches
Diameter	1½ inches
Natural Frequency	13, 17, 20 cps optional
Coil Resistance	500 ohms
Internal resistor for 0.55 critical damping.	390 ohms (20 cps) 470 ohms (17 cps) 620 ohms (13 cps)

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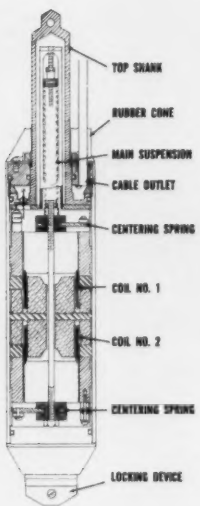

SPECIFICATIONS

S-36 Detector

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Height	17 inches
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Natural Frequency	2 cps
Coil Resistance	4000 ohms
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(Requires 10-K External Resistor for damping .5 critical)

S-36 U Detector

Coil Resistance	100 ohms
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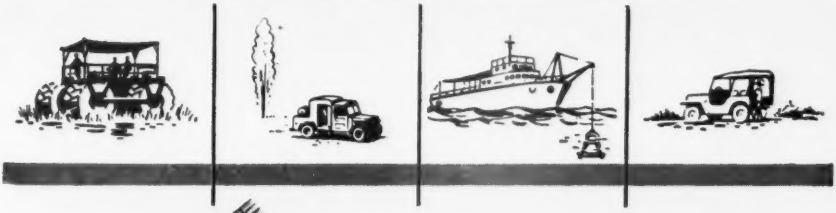

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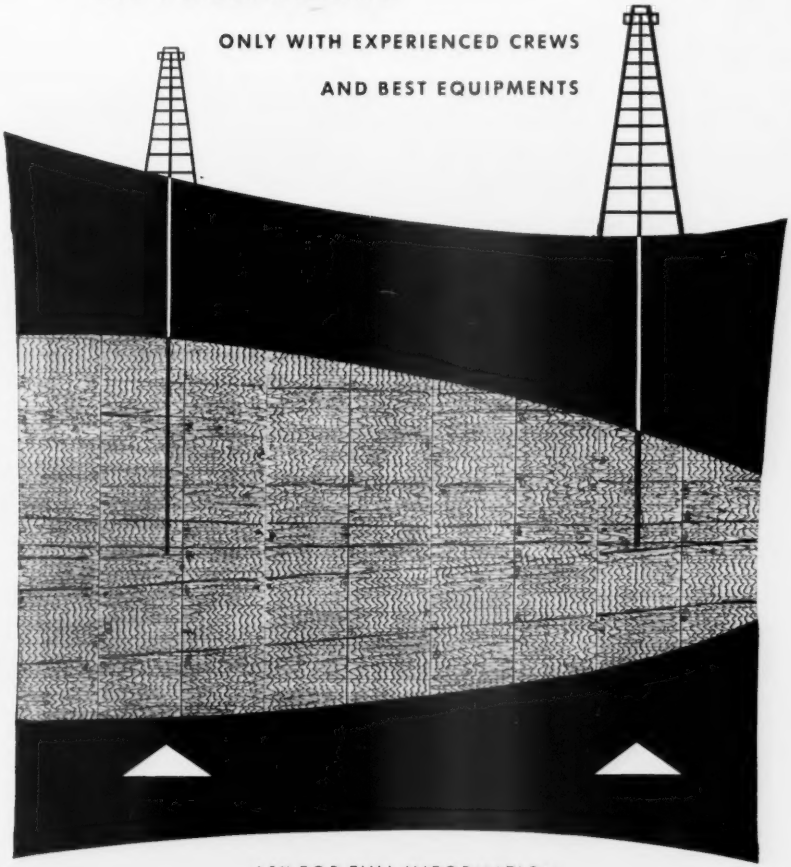

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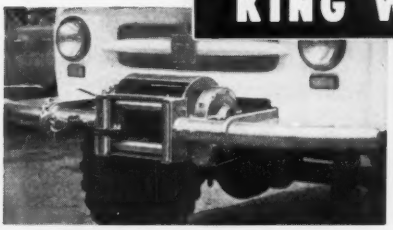

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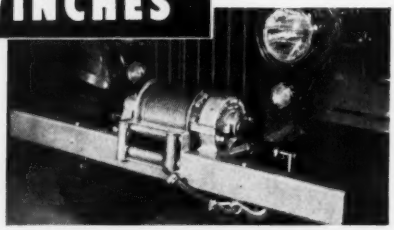

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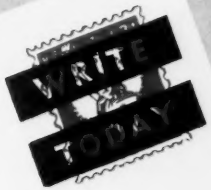

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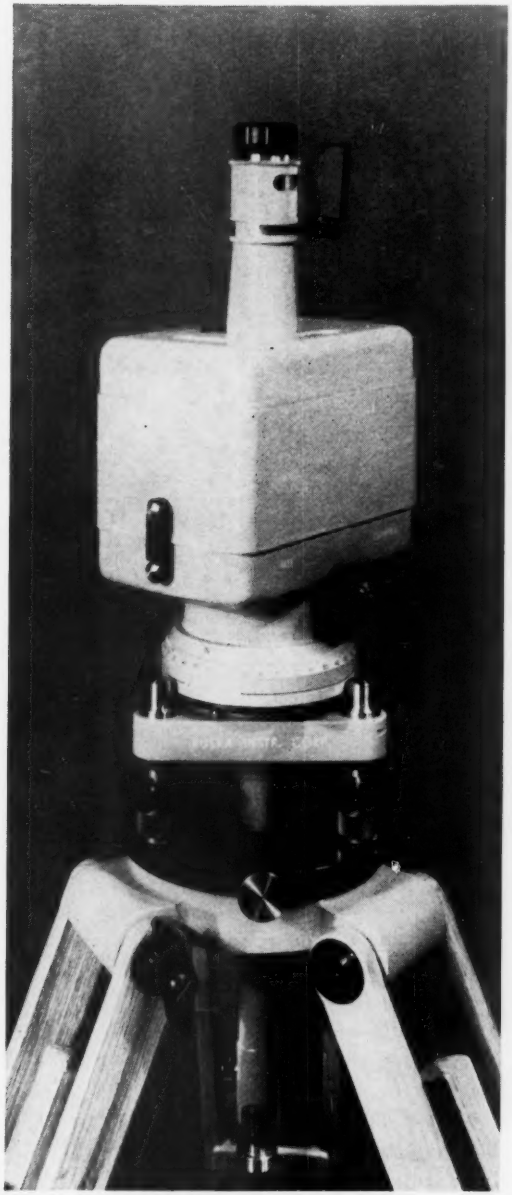

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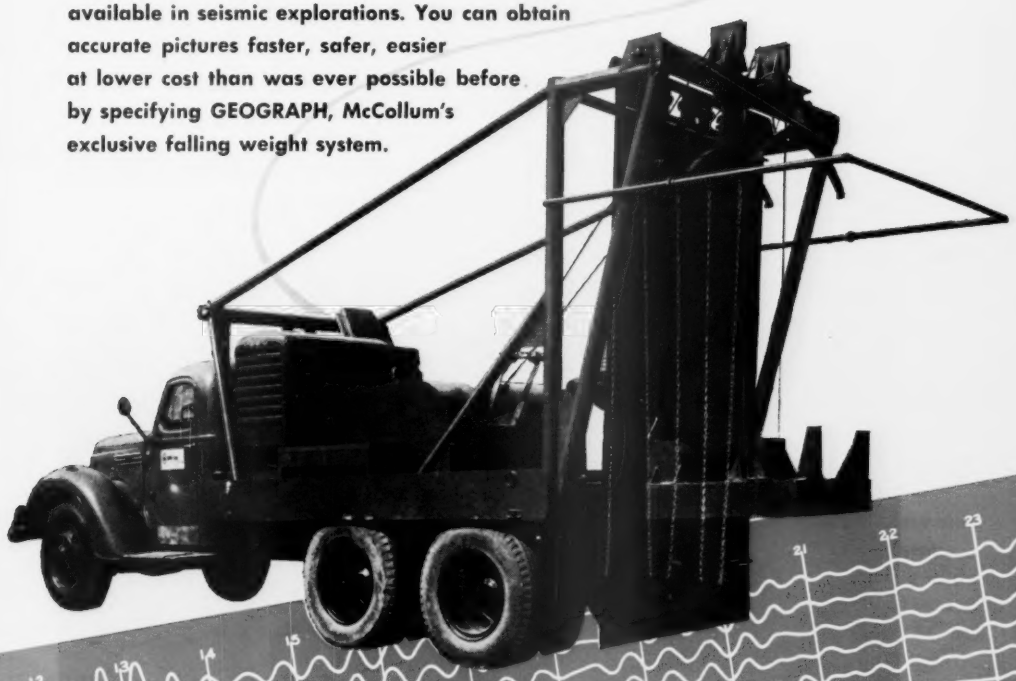

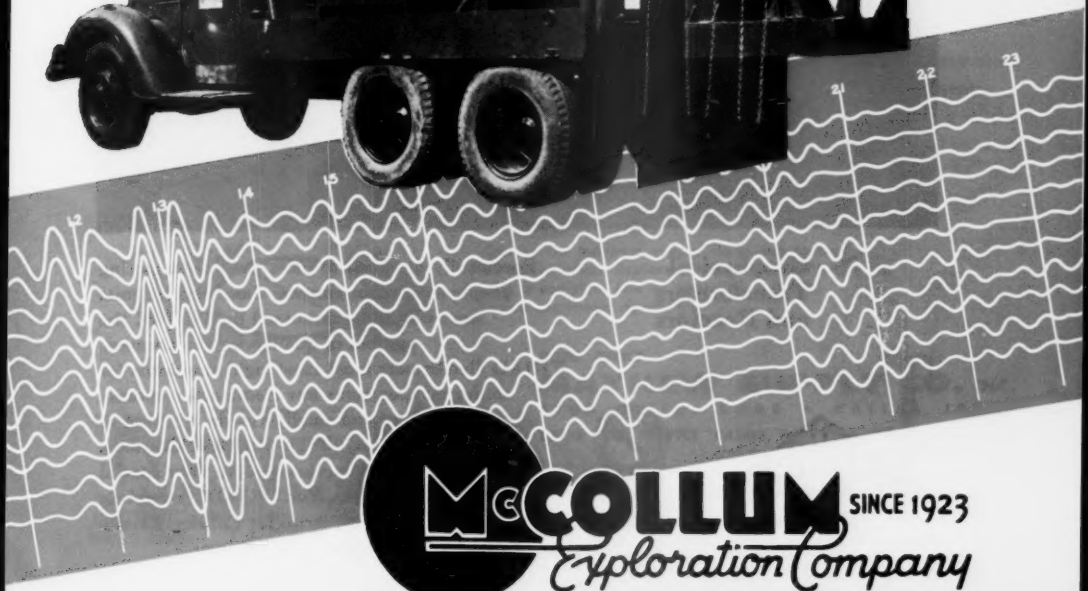

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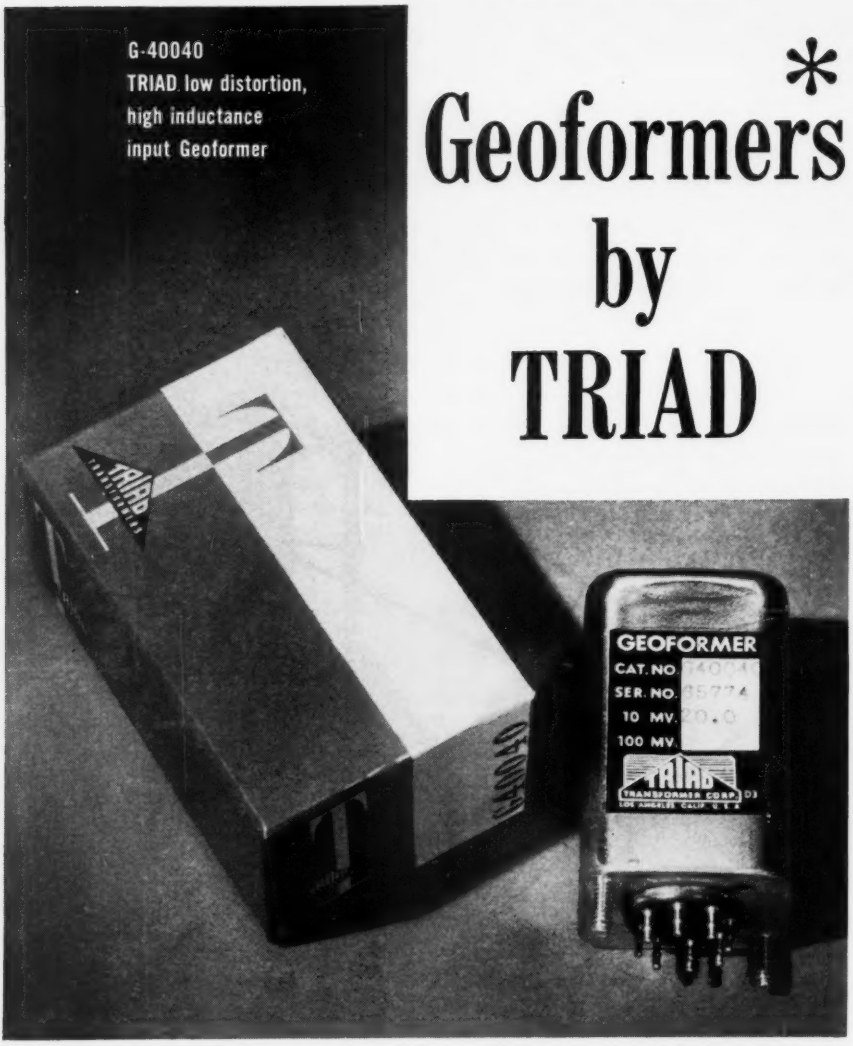

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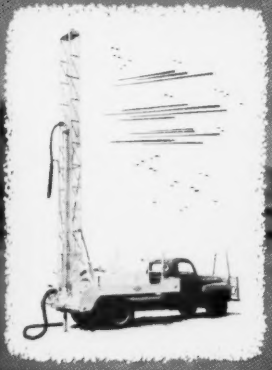

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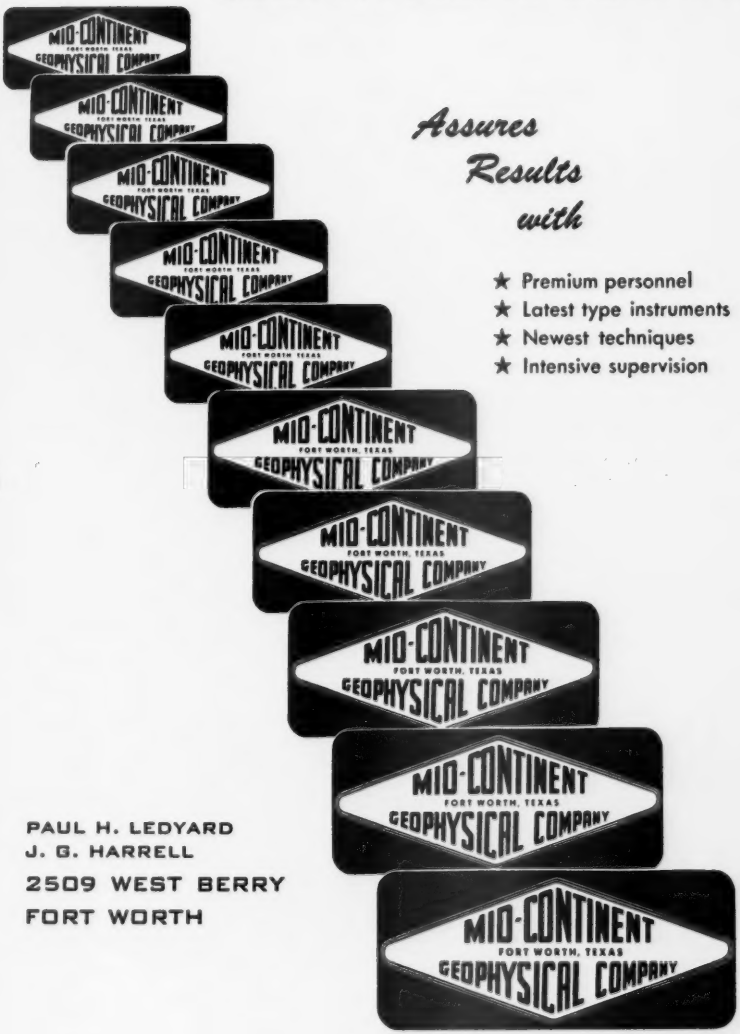

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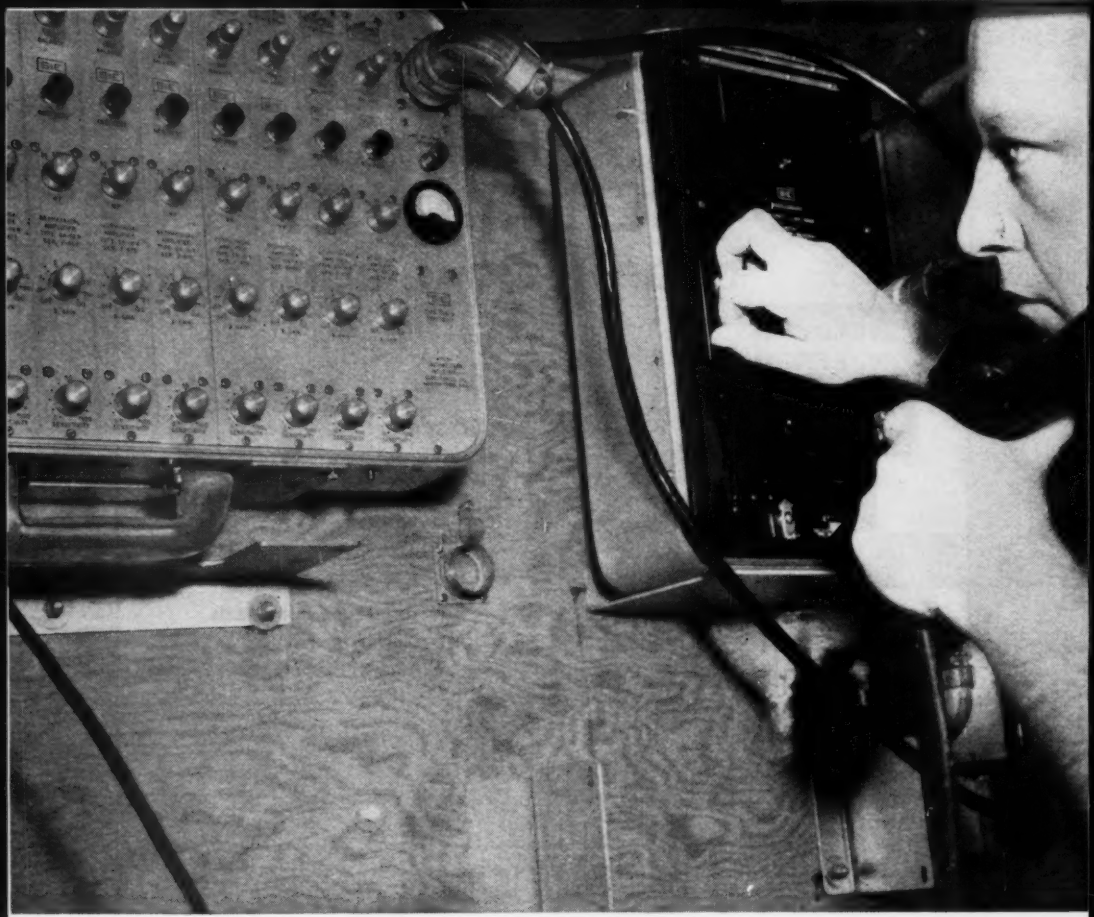

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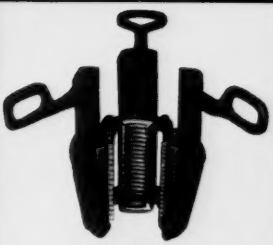

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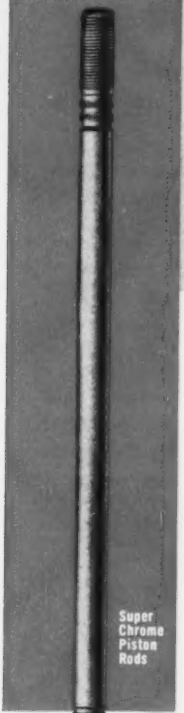

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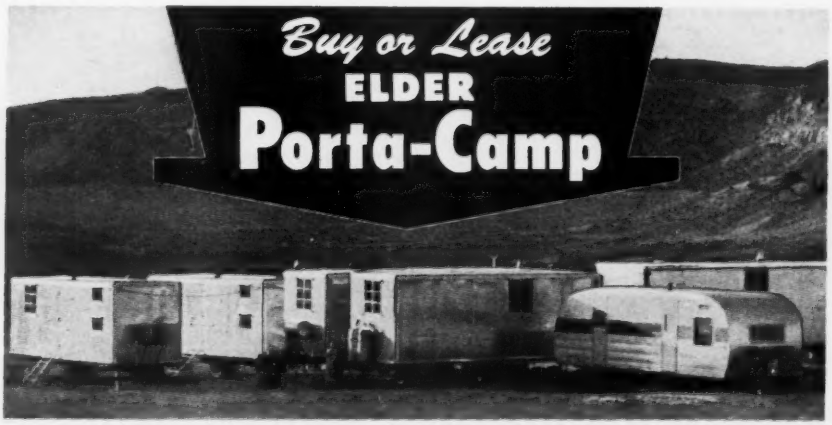

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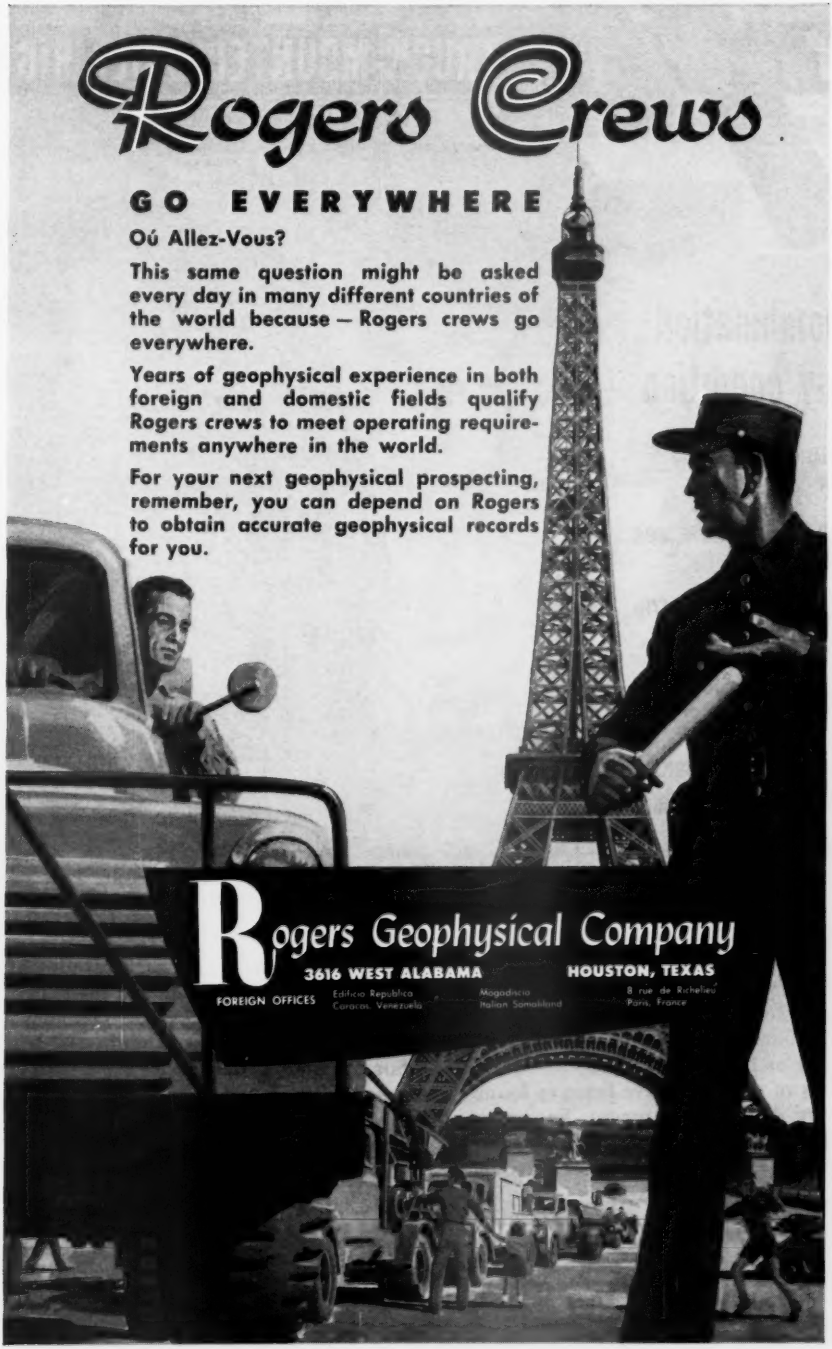
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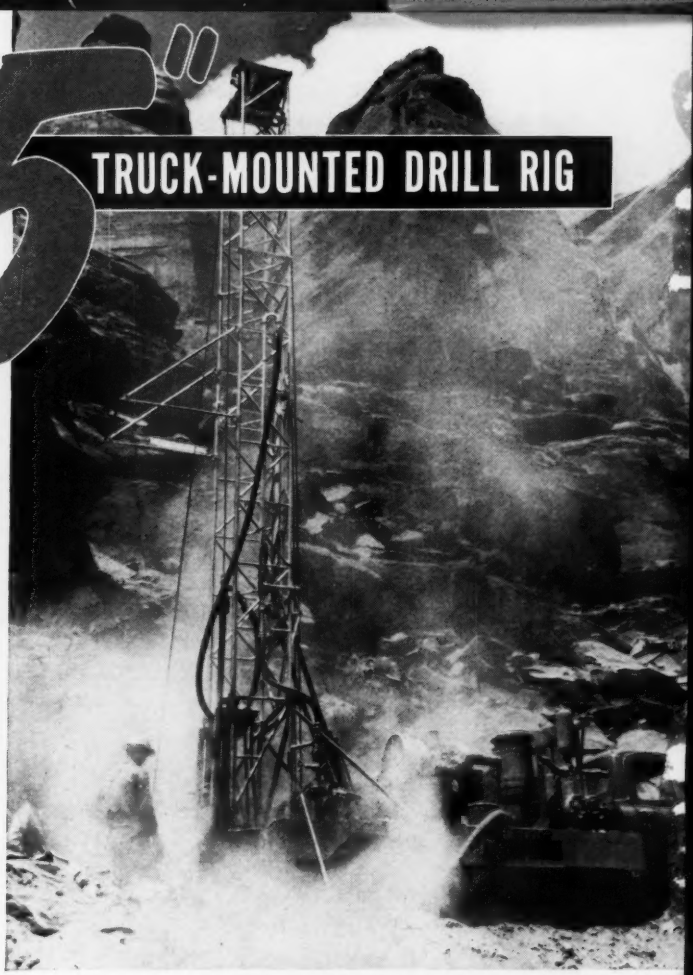

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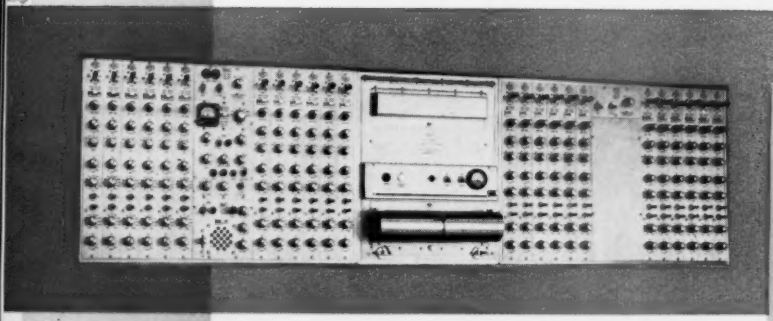

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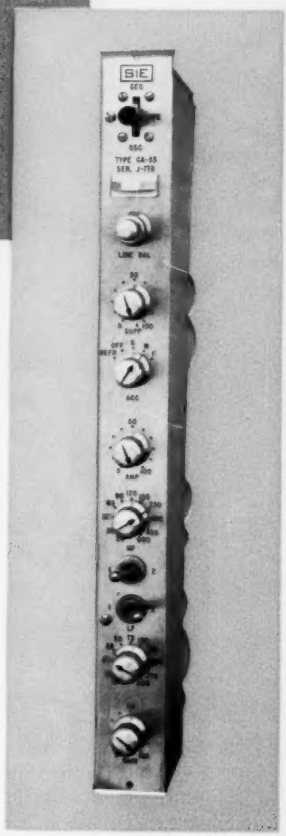

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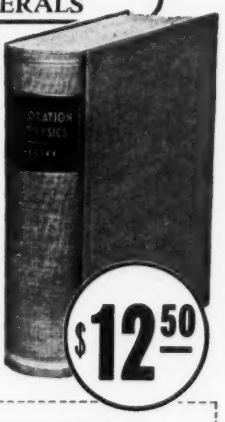

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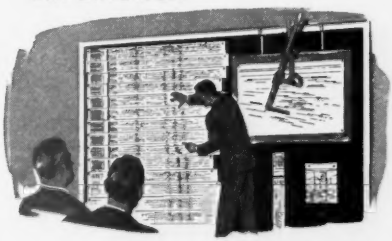

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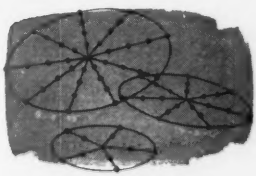

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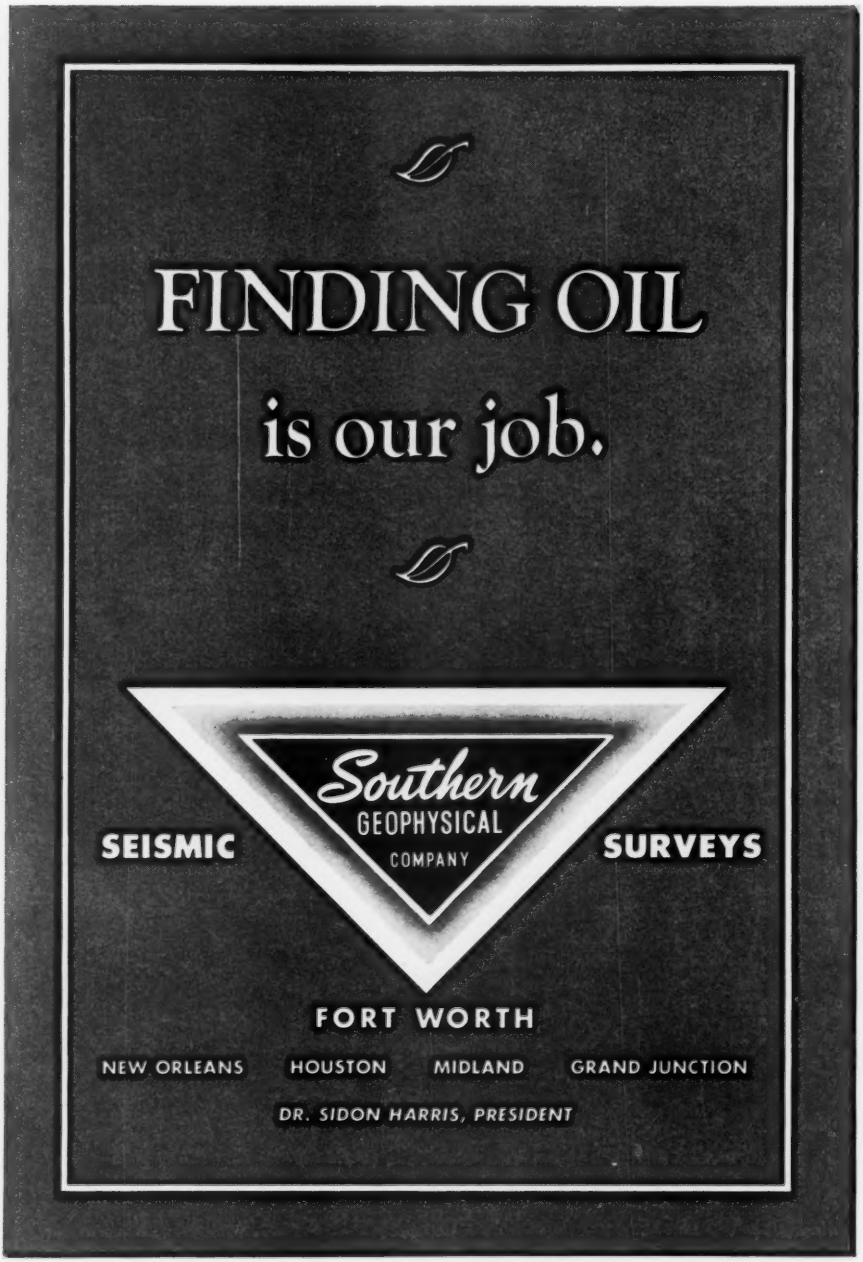
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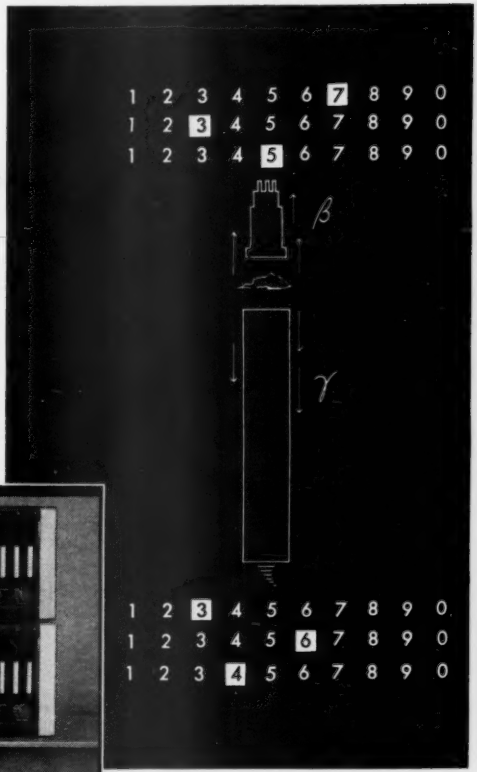

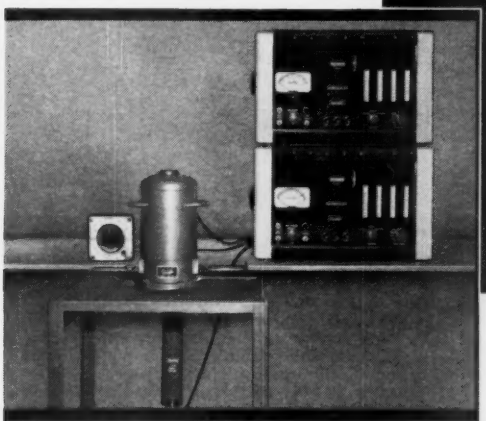

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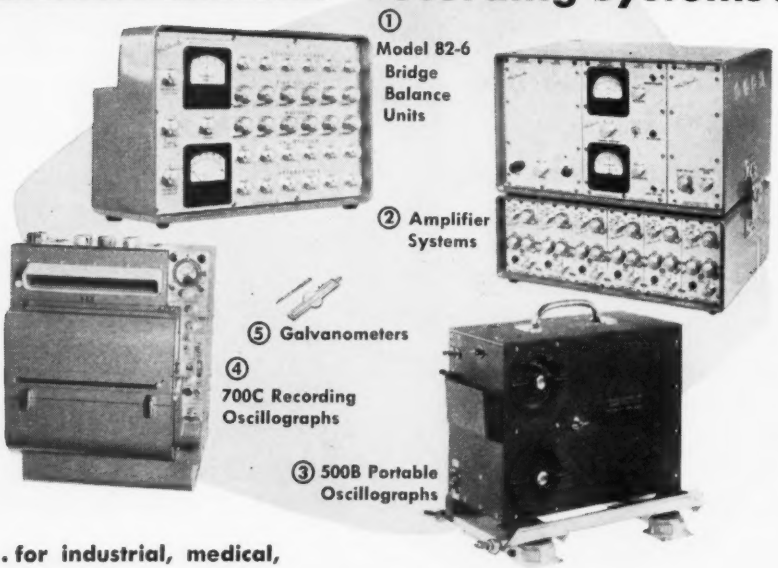

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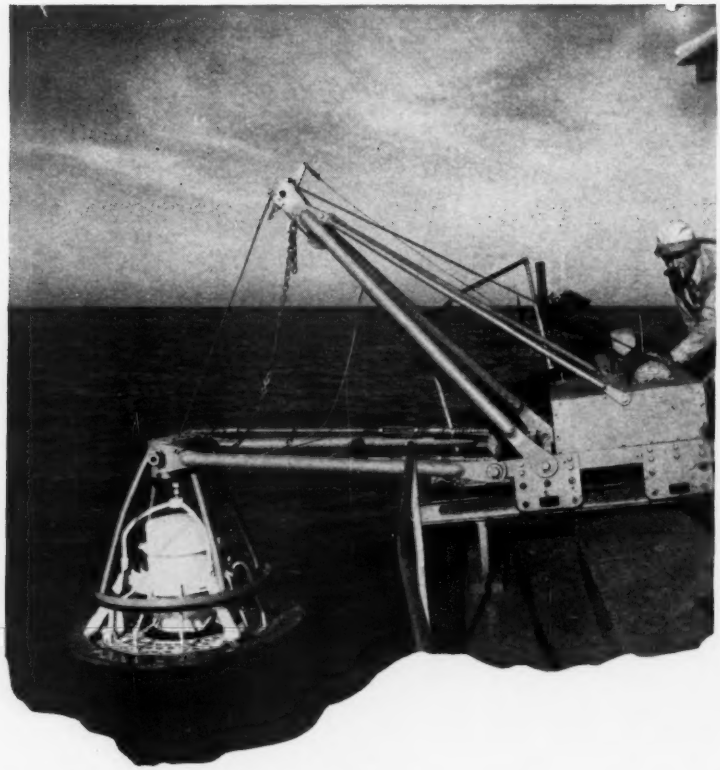

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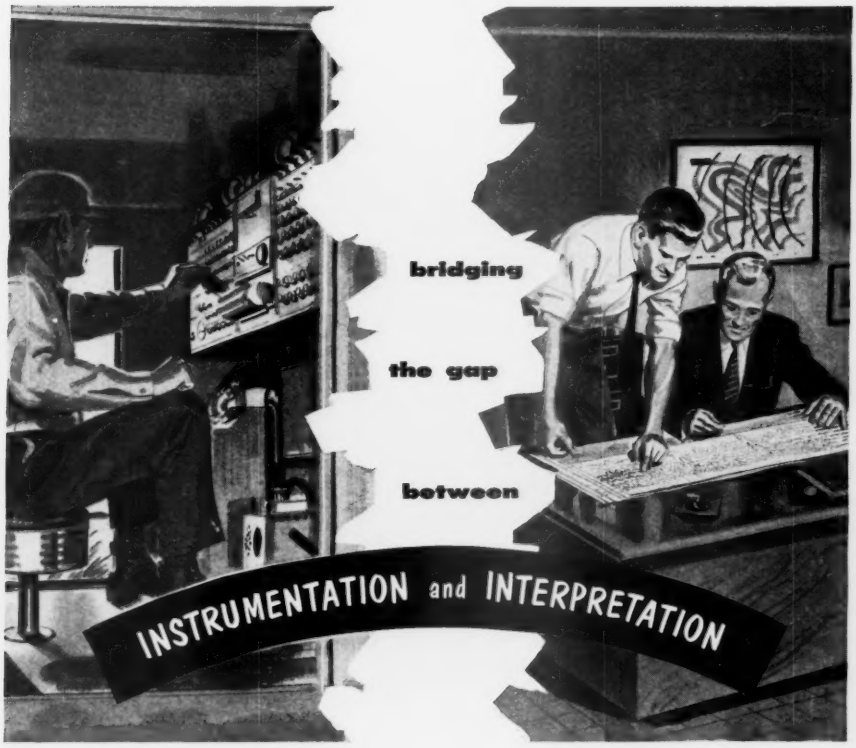

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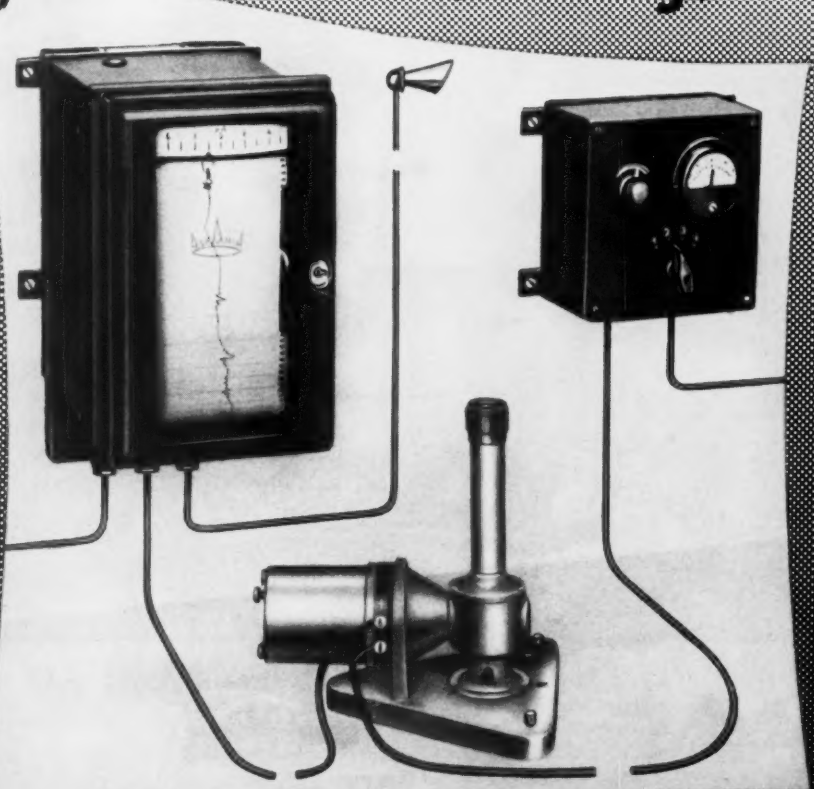

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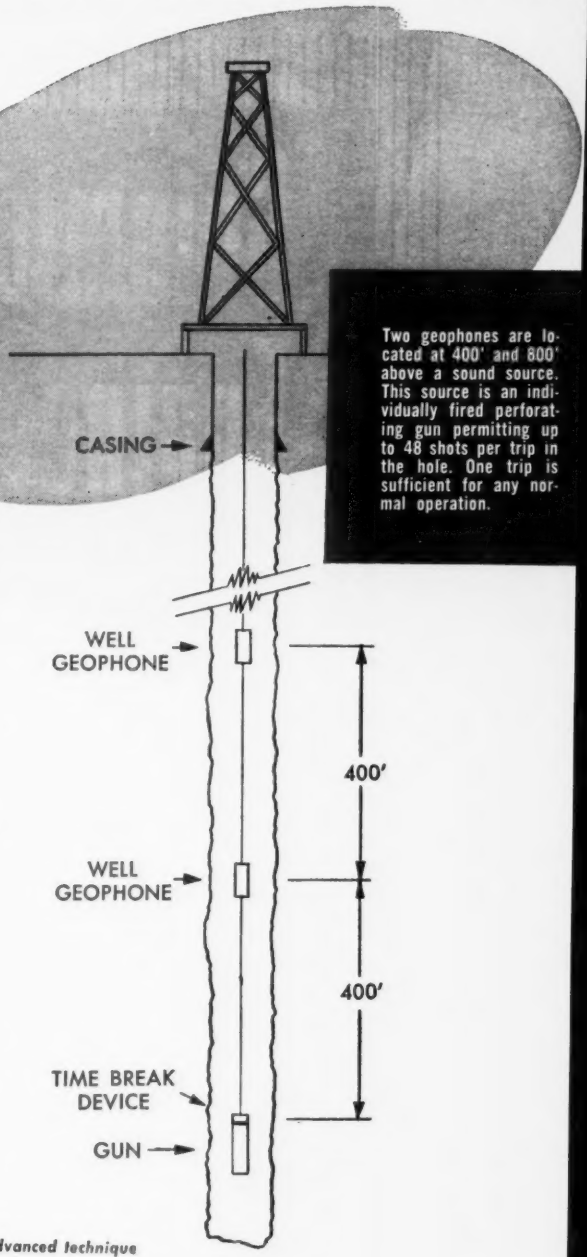

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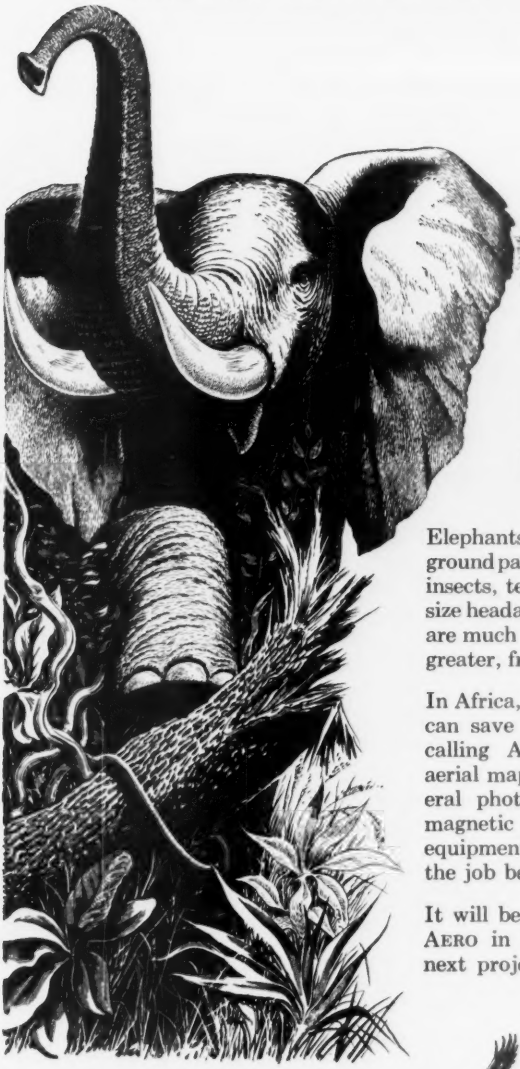

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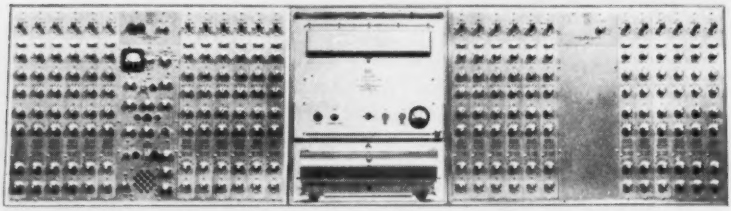

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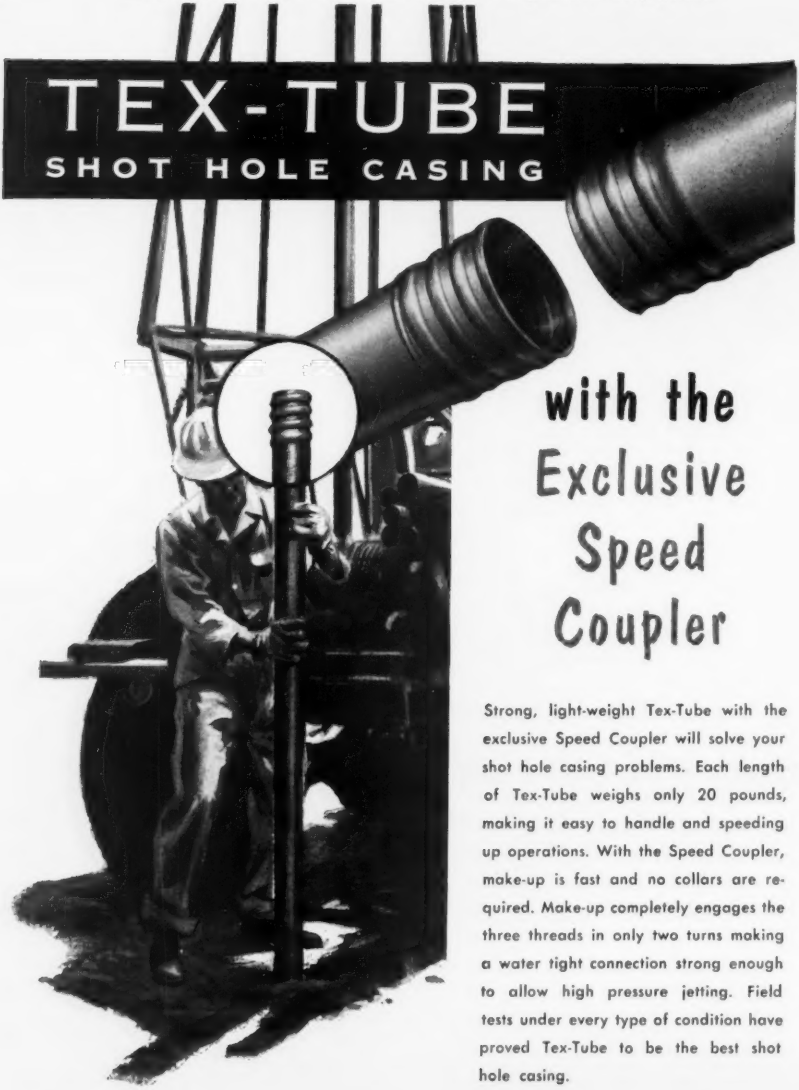

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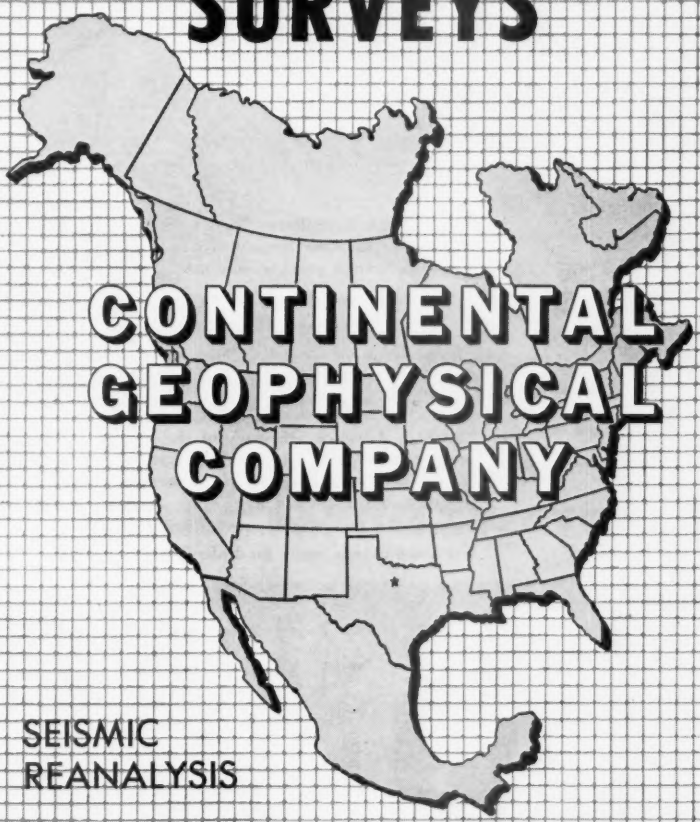

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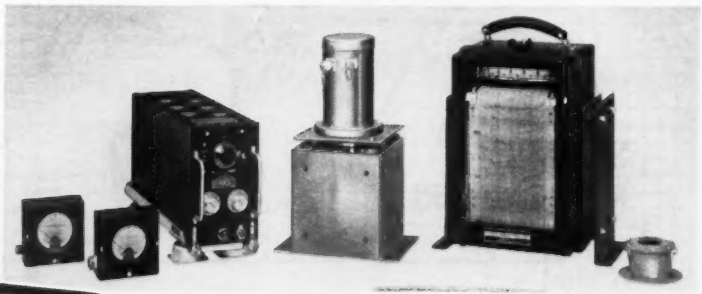

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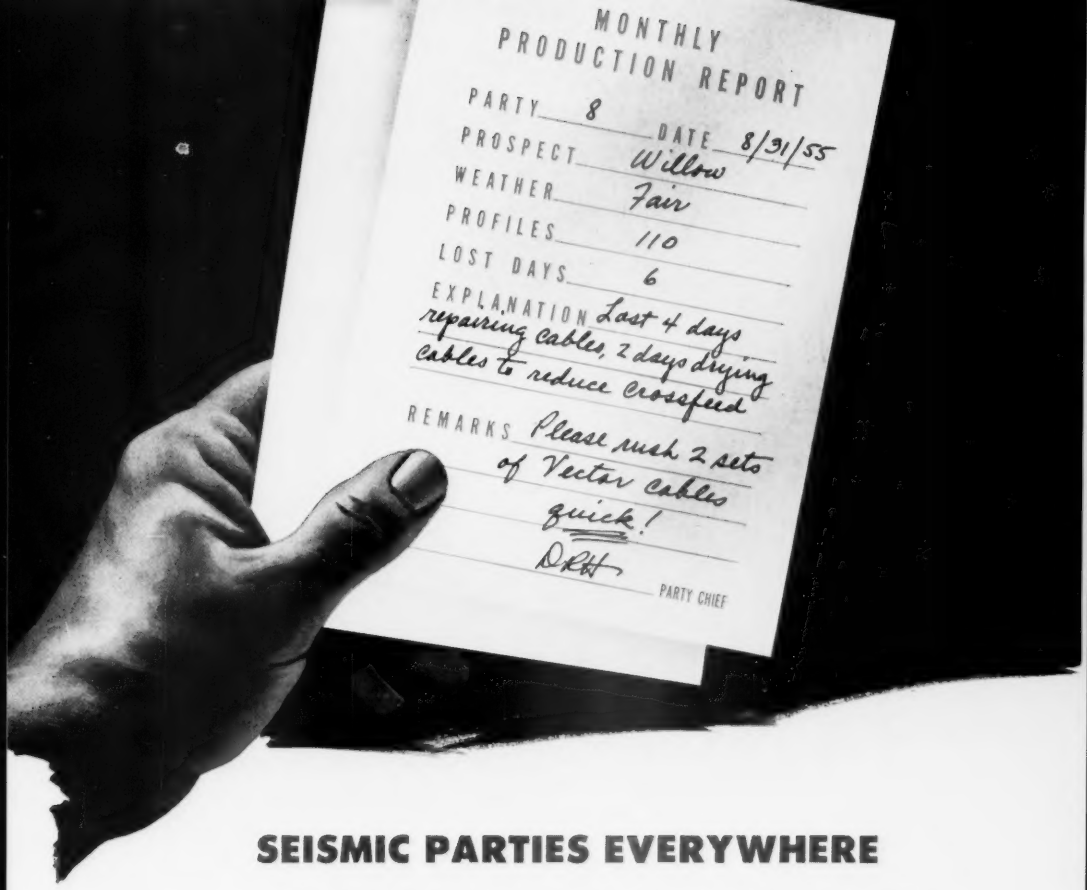

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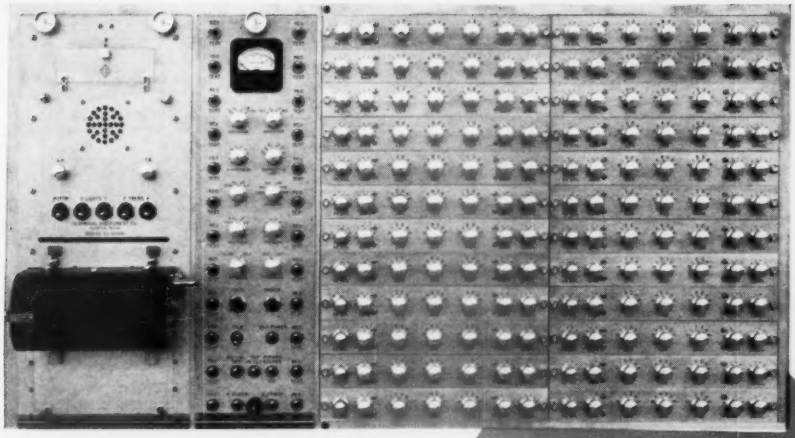

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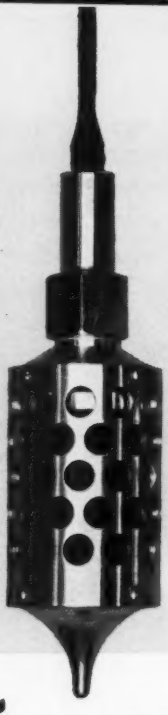

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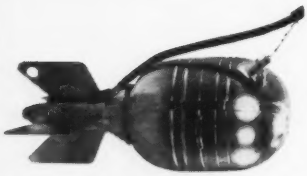


FLOATING SEISMOMETER

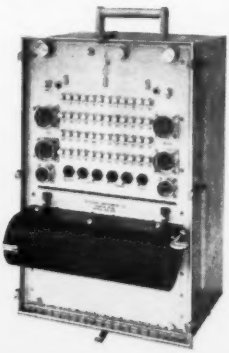
For superior operation in shallow bays where heavier inline drag cables cannot be used we recommend the Floating Seismometer, 241-F, with special stabilizing and lifting design. The special TIC damping feature which eliminates high frequency chatter is one of the main reasons why most operators prefer this seismometer.

90 VOLT BLASTER

This 90-volt blaster will fire a maximum of 6 caps. In addition to regular blaster features it has built-in communication system, 2 button firing, cap testing circuit with meter, and time break adjustment (a pulse less than 6 milliseconds long will produce a break clearly defined).

50 TRACE OSCILLOGRAPHS

TIC Recording Oscillographs are available with or without Galvanometer level controls on the front panel. When the water-tight stainless steel lid is in place, all controls, switches and plugs are protected. Designed for long service with minimum maintenance.

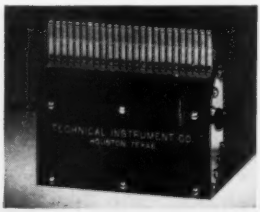


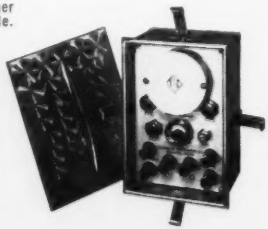
MARSH SEISMOMETER

Used in multiple strings, the TIC Marsh Seismometer, 241-ML, simplifies field checking. Here expensive external strain members may be eliminated since conductors and anchor are rated at 300 lbs. tensile strength. Fitted with a solid brass or aluminum housing case. A waterproof plug-in connection with an "idiot-proof" method of polarization. These seismometers are getting records in some areas previously considered NR (no record). 1½" x 6" — wt. 20 oz. — any reasonable length leads provided.

6 TO 50 ELEMENT GALVANOMETERS

High quality — low cost multiple element Galvanometers. The standard 15 ohm 140 cycle element gives 7" deflection per milliampere at 12". The spherical mirrors have a 10" radius of curvature. First surface .040" wide x.115" long. Other focal lengths and frequencies available.





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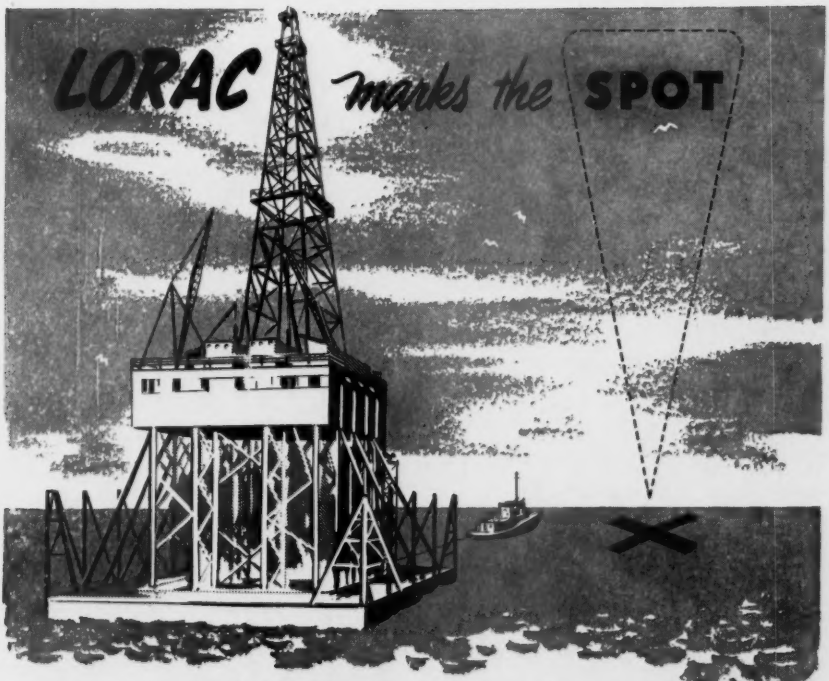

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